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X.—*On the Action of Steam in Cornish Single Pumping Engines.*

BY JOSIAH PARKES, M. INST. C. E.

Read June 16th, 1840.

Introduction.

It is generally believed and admitted by engineers that some economy is derived from working steam expansively; that is, by introducing the steam upon the piston of an engine at a pressure exceeding the force of the resistance opposed to it—by stopping its further entrance into the cylinder at some portion of the stroke—and, finally, by allowing it to expand to the end of the stroke, when it quits the cylinder at a pressure less than that of the resistance.

By the term, economy, is meant the increase in the quantity of action, which results on the expenditure of a given weight of water as steam, thus applied, compared with the quantity of action which results on the same weight of water as steam being used unexpansively; that is, at a pressure throughout the stroke forming a constant equilibrium with the resistance.

Notwithstanding, however, the length of time which has elapsed since the principle of expansive action has been practically applied, the amount of economy obtained therefrom still continues to be disputed, and its advantage even altogether denied. The opinion still finds adherents that the effect of any given weight of water as steam will be identical, whether it be introduced into the cylinder, gradually, at a pressure counterpoising the resistance, and following up the piston with the same pressure till the stroke be completed; or, whether it be introduced at a higher elasticity during only a portion of the stroke, and suffered to dilate to the end of it. This doctrine is equivalent to the assumption that, at the termination of the piston's course, the cylinder, on both principles, must be filled with steam of the pressure of the resistance. If such were the case, the quantity of action resulting from equal weights of water as steam throughout a stroke, would necessarily be the same on both systems, and no economy could result from the expansive principle.

This, then, is a question of fact, determinable by ascertaining the elastic force of the steam when it quits a cylinder, and by comparing that force with the absolute resistance overcome.

Cornish System.* The Cornish engineers have constructed the largest sized, and greatest number of engines on the expansive principle. They early adopted a system which, in their belief, carried with it practical proofs of its advantage. They augmented the pressure of the steam in the boiler; they introduced this steam into the cylinder, by opening the admission valve very suddenly, and fully, instead of gradually; they intercepted the steam's further entrance, when but a small portion of the stroke was performed; they used cylinders of large capacity, and caused the steam to develope a considerable part of its action on the piston, whilst expanding from its initial, to its terminal elasticity.

Perceiving an increased effect to be the consequence of these methods and contrivances, they have apparently cared little about the theory of the steam's action, or explanation of first causes. They have contented themselves, during a long series of years, with referring—as a sufficient refutation of the opinions of their antagonists—to the evidence of the economy of expansive action, afforded by the relative performance of equal measures, or weights of coal consumed, according as the steam was applied more or less expansively, or unexpansively.

Disbelief in the statements of these practical men would have long since vanished, if the consumption of water which entered the cylinders as steam, had been regularly used, or even occasionally resorted to, instead of fuel, as the standard of the engine's performance; for, whilst the construction of the engine, and application of the power were modified, the evaporative product from a given weight of coal was increased: the machinery of pumps and pitwork was also constructed on more effective principles. Thus, the progressively increasing performance of the Cornish engine, though in fact arising from various sources, was referred, on the one hand, solely to the use of expansive steam, and, on the other, set down as unworthy of implicit faith.

The general truth of the statements of Cornish duty has always appeared to me indisputable, nor could I doubt the numerous facts reported by other engineers, corroborative, in a greater or less degree, of the economy attributable to the expansive system. It seemed to me that any experienced practical man

* An excellent engraving of Davey's engine, Consolidated Mines, from drawings by Mr. John Hocking, appeared in the "Annales des Mines," vol. v. 1834, with a clear description of the structure of its several parts by M. Combes, Ingenieur des Mines. This is the only published account of the action of a modern Cornish pumping engine with which I am acquainted.

was capable of determining the head of water against which an engine worked, and of reducing it to the terms employed in practice. Nevertheless, I have been at a loss to account for the greatest assigned performances of these engines. I gave full credence, after a patient investigation of the experiments, to the fact of the stated effects; but was unable to trace them, in the highest range of duties quoted, solely to the increased quantity of action obtainable from steam, expanded only to the extent assigned by the reporters of the experiments.

Data required for investigating the steam's action. Until very recently, the data necessary for the satisfactory determination of Cornish economy remained unknown, or were not collected. We possessed no record of exact experiments made at any one expansive engine, whether single or double acting, on the quantity of water, in the shape of steam, which had passed through the cylinder during an observed number of strokes; whence, alone, the relation which the steam's mean force bore to an ascertained resistance could accurately be deduced. A knowledge of the duty, or effective performance of an engine by a given weight of coal is, obviously, no criterion of the expenditure of power; it sheds no light on the steam's action in the cylinder; nor do the periodical returns of Cornish duty, however practically useful, afford data for determining the absolute resistance overcome by the steam.

Huel Towan engine. Mr. Henwood's communication (Trans. Inst. C. E. vol. ii.) contains, I believe, the first published observations on the quantity of water as steam consumed by a Cornish single pumping engine. These were made on the Huel Towan engine. The fact was elicited that the steam's elastic force in the cylinder was far from being uniform during the period of its admission, but that it was in a state of expansion from nearly the beginning to the end of the stroke. This result is manifested by the indicator diagram obtained from that engine.* A similar action was denoted by the instrument in several other engines to which it was applied.

He noticed the fact of the steam's elasticity at the end of the working stroke being unable to sustain the column of water; and recorded numerous quantities, and observations, of much interest and assistance in the present research.

With respect to the determination of the load of water, he twice measured the height of the lifts himself, and twice ascertained the whole water delivered

* This previously unnoticed phenomenon is referred by Mr. Henwood (see his paper, p. 50) to the diminishing elasticity in the boiler (see Note to p. 272, also my last paper, Trans. Inst. C. E. vol. iii. p. 61.)

by the pumps of the Huel Towan engine to correspond with the calculated quantity within less than 8 per cent.*

Fowey Consols engine. The next engine for which the consumption of water as steam is satisfactorily ascertained is the one at the Fowey Consols, which accomplished the greatest duty yet reported.† The evaporation was not determined by the committee who conducted the trial, but, subsequently, by Mr. West, the maker of the engine, in the manner stated in my last paper (pp. 62, 63).

Holmbush engine. Mr. Wicksteed's experiment on the weight of water actually delivered by the pumps of the Holmbush engine, confirmed Mr. Henwood's accuracy at Huel Towan; and as the duty at Holmbush‡ nearly approached that at Fowey Consols, it afforded additional testimony to the authenticity of the stated performance of the latter engine. Mr. Wicksteed, unfortunately, did not ascertain the expenditure of water as steam during his experiment, a datum which I have supplied, for the purposes of this investigation, by assuming a consumption based on an equal evaporation to that effected at Fowey Consols and Huel Towan, viz., 10·5 lbs. of water converted into steam by 1 lb. of coal.

Analysis.

The Huel Towan, Holmbush, and Fowey Consols experiments analysed. The preceding results form the subject of the present analysis, undertaken in the hope of discovering, from the known consumption of water as steam, the whole quantity of action developed by it—its action, had it been used unexpansively—the precise value of its expansive action—and the correspondence between the appreciable power and effect, in each engine. The loads of water, dimensions of the engines, number of strokes, consumption of water as steam, and other necessary data are registered in the annexed table.

The absolute effect of the steam, in these examples, is not so readily determinable as the absolute power exerted by it. The rods suspended to the beam of a Cornish engine perform the pumping or return stroke. Their

* The duty effected during Mr. Henwood's experiments in 1831 was 81·389 millions. On a shorter trial in 1830 the duty was reported as 92·33 millions; and in 1828, during a trial of 26 hours, 87·20 millions. The near correspondence between the calculated and actual quantity of water discharged by this engine, has also been ascertained by other experimenters.

† 125·089 millions. For an account of the trial of this engine see "Lean's Historical Statement of the Steam Engines in Cornwall," p. 98.

‡ 117·906 millions.—See Mr. Wicksteed's paper, Trans. Inst. C. E. vol. ii.

weight must, therefore, be superior to the column of water on which they act, by the amounts necessary to overcome the friction of the water in the pipes—to displace it at the velocity of the stroke*—to overcome the pitwork friction arising from the pumps, rod-guides,† balance beams, &c.—and the friction of the engine itself.

This mass of matter constitutes the solid weight raised by the engine, but does not equal the absolute resistance opposed to the steam. In bringing back this weight, during the working, or descending stroke of the piston, the steam has also to overcome the whole amount of engine and pitwork friction, together with the resistance from imperfect vacuum beneath the piston.

Determination of the absolute resistance. The absolute resistance, therefore, consists of the weight which performs the return stroke, plus the value of engine and pitwork friction, and of the elasticity of the uncondensed steam. The method of correctly ascertaining this resistance, which is the steam's effect, will be shewn in the sequel (p. 280).

Of the several component portions of the total resistance, the water load can alone be termed a positively ascertained quantity. This is found by the method of taking the duty, and amounts for each engine to the following sum:

* Mr. Henwood's paper supplies data for determining the velocity of the water in the pipes at Huel Towan. The return stroke was performed in 4·8 seconds, and the length of stroke in the pumps being 8 feet, the discharge was effected at the rate of 1·666 feet per second, or 1·13 miles per hour.

The entire column of water displaced at that velocity was 899·07 feet in height, and the mean diameter of the pumps 14·625 inches. The pipes are usually larger than the pumps, but the friction of the water is often greatly increased in the lifts by incrustation from mineral deposits. Mr. Henwood informed me that he has seen pipes of 9-inch bore diminished to 5 inches from this cause.

Mr. Moyle, an experienced Cornish engineer, has also informed me that he has known pipes of 14 inches bore reduced to 12 inches by a coating which consisted chiefly of oxide of iron, mixed with a little copper, and carbonate of lime.

I am not aware of any experiments made with the view of determining the head or pressure requisite to force water through pipes at different velocities, circumstanced as mining pumps are. It is, however, manifest that in order to give a velocity of 1·13 miles per hour to a column of water 900 feet high, the pump rods, besides being heavy enough to balance the column, and overcome friction of all kinds, must also have a preponderance sufficient to drive the water at the required velocity.

Mr. George Rennie, in his Report on Hydraulics, cites some experiments by Mr. Tierney Clarke to shew that "the friction and resistance of the pipes to the free motion of the water through them have been found to be between one-fourth and one-fifth of the total height of the column."—*Fourth Report of the British Association for the Advancement of Science*, p. 416. This seems a large consumption of power for water friction, but the velocity of discharge is not stated, which is probably in most cases greater in a waterwork than in a mine engine.

† "The rods of the Wheal Towan engine varied from 14 to 12 inches square, and were kept in their places by 13 sets of guides, which exposed a surface of about 53·5 square feet."—Henwood.

Per square inch on the piston. lbs.	
*11·01	at Huel Towan.
9·98	at Holmbush.
9·26	at Fowey Consols.

The value of the various frictions being unascertained, I am compelled, in the outset of the investigation, to assume an equivalent, and have estimated them to amount to 5·75 lbs. per square inch on the Huel Towan engine. To this has to be added the resistance from imperfect vacuum beneath the piston, which I assume as 1·25 lb. per square inch; forming a total of 7 lbs. per square inch in addition to the water load.

As the other two engines were not burthened with so high a column of water, I have assumed about 6 lbs. per square inch for these additional resistances.

I consider these amounts to be under rather than overrated, and shall, subsequently, offer evidence, amounting to demonstration, that the steam had to overcome, in the Huel Towan engine, a somewhat greater resistance than that now assigned. It will appear, too, that though the quantities set down as the value of these surplus resistances can be considered only as approximations, they will not affect the accuracy of the principal facts developed by the analysis.

The absolute resistance thus assumed to be overcome by the steam is—

Per square inch on the piston. lbs.	
18·01	at Huel Towan.
†16·00	at Holmbush.
15·25	at Fowey Consols.

* Erroneously printed 10·2 lbs. in Mr. Henwood's paper.

† Mr. Wicksteed (see his communication previously quoted, p. 64) has estimated the "friction of the machinery" of the Holmbush engine as equal to 7·75 lbs., and the resistance from imperfect vacuum as 1·50 lb., making 9·25 lbs. per square inch on the piston; which, added to the water load, would bring the absolute resistance of this engine to 19·23 lbs. It will, hereafter, be seen (note p. 275) that an erroneous datum of the steam's density in the cylinder, during its admission, led to this estimate.

The same author cites "the friction of a waterwork pumping engine as about 5·75 lbs. per square inch," but, whether this sum includes the friction of the water in the pipes, or, whether it is only "the friction of the machinery," is not stated. These amounts should be separately determined by experimenters.

Determination of the steam's elasticity at the end of the stroke. The area of the pistons, and length of stroke being known, the volume of steam contained within the cylinder is a determinate quantity; and the whole quantity of water consumed as steam being divided by the observed number of strokes, the volume of water which produced that volume of steam is obtained. The ratio which these volumes of steam and water bear to each other, supplies the fact of the steam's elasticity at the end of the working stroke.

By the same method, its elasticity is ascertainable at any other portion of the piston's descent, after all the steam has entered the cylinder. The pressures corresponding with these ratios are taken from M. de Pambour's useful and compendious table, in his "New Theory of the Steam Engine," p. 74, which is extracted into my last paper, p. 122.

By this method it is found that, on the termination of the working stroke, the steam possessed an elasticity of—

Per square inch on the piston. lbs.	
7·30	at Huel Towan. (App. 1.)
4·60	at Holmbush.
3·95	at Fowey Consols.

So that, in no one case was the steam's pressure, at the end of the stroke, able to sustain the column of water alone, much less to counterpoise the absolute resistance. The difference between the opposing and active forces, on the termination of the stroke, was—

Per square inch on the piston. lbs.	
10·71	at Huel Towan. (App. 9.)
11·40	at Holmbush.
11·30	at Fowey Consols.

The steam's expansive and unexpansive action separated. The next step in the inquiry is the separation of the value of the steam's expansive action, from its action, had it operated unexpansively, throughout the stroke. These respective values are accurately determinable by the same method of analysis, which will also shew whether their sum equals, exceeds, or falls short of the absolute resistance overcome.

Before entering upon this inquiry, however, it will be well first to consider the manner in which the steam operates.

At its entrance into the cylinder, the steam's pressure exceeds that of the force opposed to it, or the engine would not stir; at the termination of the stroke, its pressure is reduced below that of the resistance, as already found; nevertheless, the sum of the forces operating throughout the stroke must be sufficient to carry the piston to the end of its course, or it could not arrive there.

The mass of matter set in motion by the steam's initial force on the piston, acts the part of a fly-wheel. It first absorbs the excess of power over the resistance, and then faithfully discharges it, by assisting to continue the engine's motion during the steam's expansion, and consequent diminishing force, below the pressure of the resistance. But this mass of matter possesses no power-creating virtue; it merely husbands at one period of the stroke, and restores at another, that force which has been given to it; it exerts no power of its own.

From a due consideration of the origin and destruction of the momentum arising from this source, it is evident that the effect of a given weight of water as steam, consumed during a stroke, will be the same, whether that steam be regarded as having been all enclosed between the piston and cylinder cover, before the piston were permitted to move, when it would expand nearly uniformly from the beginning to the end of the stroke; or, whether it be considered as having been admitted during a portion of the stroke, at some pressure greater than the resistance, and then expanded through the remainder of the stroke.

But, the value of expansion consists, virtually, in the quantity of action derived from the steam, after it forms an equilibrium with the resistance. This, then, is the first point to be ascertained. By investigating the steam's action on this plan, that is, by tracing it, first, through the space of the cylinder, or portion of the stroke performed, when it would barely balance the resistance; and, secondly, through the space during which it suffered expansion below that pressure, a true measure of the respective and total quantities of action developed by it, unexpansively and expansively, will be obtained. This is the only analytical process which can detect the quantities sought, for we are uninformed either of the steam's mean elastic force during the term of its admission into the cylinder, or, of the exact period of the stroke at which its further admission was stopped.

The portion of the stroke at which the steam's pressure equalled that of the

resistance, is discoverable by the method of the volumes; for, the volume of water composing the steam within the cylinder being known, the volume which the steam must occupy, in order to balance the resistance, is also known; and the increment of the stroke, which gives the necessary capacity to the cylinder, is found from the ratios which the volumes of steam and water must bear to each other for the required pressure.

It results that, when the piston of the Huel Towan engine had passed through 50·70 out of 120 inches (Appendix, 2), which was its total length of stroke, the steam's elastic force and the resistance counterpoised each other. The equilibrium was established in the Holmbush engine at 32·26, in a stroke of 109 inches; and in the Fowey Consols at 33·78, in a stroke of 124 inches.

It is thus manifest that, at these respective portions of the strokes of the three engines, the steam, if used unexpansively—that is, if admitted gradually, at the pressure of the resistance—would have done its utmost, and the engines would have come to rest; yet there remained 69·30 inches in the first engine, 76·73 inches in the second, and 90·22 inches in the third, of the entire stroke to be accomplished. These last portions were performed during the steam's expansion from an elastic force equal to the resistance, to the elastic force it possessed at the end of the stroke.

It is through these portions of the stroke that the expanding steam is assisted by the discharge of the momentum transferred to the mass by the excess of the steam's force over the resistance, during the period intervening between the instant of its entering the cylinder, and the instant when its elasticity falls below the resistance. The value of this temporary excess of force forms part of that attributed to the expanding steam, as no expansion could have taken place below the line of equilibrium between the acting and opposing forces, but for the momentum husbanded and restored. (App. 10, *Obs.*)

The spaces through which the pistons were urged by virtue of the action of an elastic force equal to the absolute resistance, and less than the absolute resistance, being thus separately ascertained, the quantities of action derived from each are shewn by the dynamic effect produced—that is, by the number of pounds raised one foot; and this result is obtained by multiplying the pressure on the piston, by the number of feet through which it travelled. The pressure used in computing the effect during the expansive portion of the stroke is the mean of the steam's elasticity at the commencement of useful expansion, and at the termination of the stroke.

Absolute power of the steam compared with the absolute resistance.

By adding together these unexpansive and expansive effects we obtain the whole effort of the steam, in terms of weight raised one foot; which, being divided by the length of stroke in feet, gives the mean load of steam upon the piston throughout the stroke; and this sum, divided by the area of the piston, gives the mean pressure in pounds per square inch exerted by the steam throughout the stroke.

A precise comparison is thus arrived at between the pressure of the steam on the pistons, and that of the resistance opposed to it: and it results that the steam possessed a mean force, reckoned throughout the stroke, of—

Per square inch on the piston. lbs.	
14·85	at Huel Towan. (App. 8.)
11·47	at Holmbush.
11·13	at Fowey Consols.

Whereas, as before shewn, the resistance to be overcome required—

Per square inch on the piston. lbs.	
18·01	at Huel Towan,
16·00	at Holmbush.
15·25	at Fowey Consols.

Which exhibits a deficiency of power throughout the stroke, of—

Per square inch on the piston. lbs.	
3·16	at Huel Towan. (App. 9.)
4·53	at Holmbush.
4·12	at Fowey Consols.

Deficiency of Power.

The results obtained at this stage of the investigation demonstrate that the mean force of the steam, in the cases under review, was unable to overcome the resistance; they present to us the seeming paradox that the lighter weight has raised the heavier one. But, we know that a force equivalent to the resistance must have operated throughout the stroke, or motion would not have continued.

How is it then that, in these instances, the steam's force, which may be termed the lighter weight, has actually counterbalanced the resistance and

raised the heavier weight? In this consists the seeming paradox. To attempt its explanation by saying that such an effect can be produced by the steam's mere expansive action, is to use words of no meaning; for steam, in the act of dilatation, diminishes in elastic force; and the absolute effort, exerted by virtue of the steam's initial pressure, and subsequent expansion, can only amount to that of its mean pressure reckoned throughout the stroke; and this has already been proved to be far unequal to the effect. It would be necessary to prove that steam gained, instead of lost elastic force, during the act of dilatation, in order to account for the entire performance of the engine, in these instances, by expansion alone.

It was the glimpse I had obtained of this deficiency of power—of this apparent discrepancy between cause and effect—which induced me to desist, when writing my last paper, from any attempt to illustrate the action of steam in Cornish engines. The materials for the analysis were therein given, and the data now employed furnished to those who might be disposed to investigate them. The subject seemed to me worthy of an examination distinct from the matters then treated of, and to require for its elucidation much patient thought and research; for, unless a power could be discovered to have acted commensurate with the effect produced, no other alternatives presented themselves to my mind, than a rejection of the data as erroneous, or the belief that the received theory of steam was insufficient to explain its action.

With regard to the data of power, there seemed to me much greater reason to suspect some excess in the consumption of water as steam assigned by the experimenters, than the contrary; for the evaporation cited from a given weight of coal is the greatest on record. The steam is also assumed to have been strictly pure; every particle of the water evaporated is presumed to have acted as force; no loss of any kind is allowed for. Doubt could not be entertained as to the dimensions of the engines, nor as to the number of strokes made by them during the observations; neither could suspicion of any material error attach to the elasticities deduced from the relative volumes of steam and water consumed.

With respect to the approximate datum of absolute resistance, I felt assured—from a consideration of the peculiar circumstances under which these engines work—from analogy—and from certain phenomena, to be hereafter explained—that the sum assumed as the basis of calculation was below, rather than above, the amount of absolute resistance opposed to the steam.

The dilemma was perplexing, but I felt animated in the further investigation of this mysterious discordance between the appreciable power and effect, by the reflection that, like the celebrated hydrostatic paradox, the problem might admit of solution; and that some new light might be shed upon the science of the engine. I was thus finally led to doubt the sufficiency of the ordinary theory to account for the whole power exerted by steam, and was induced carefully to examine its action under the peculiar circumstances of its application to Cornish engines, in the hope of discovering the force which made up the complement of power necessarily exerted in overcoming the resistance.

I will now proceed to develope the opinion I have formed on this subject, together with the facts and arguments in support of it.

Theory of the Steam's Action.

Steam, in its action on the piston of an engine, has hitherto been considered as simply exerting elastic force.

Percussive Action of Steam. Steam, however, possesses another important property, equally inherent in its nature with pressure and expansibility. This property is the velocity and consequent momentum due to steam of high elasticity; a force which comes into play under the peculiar conditions of a Cornish engine. The velocity of steam, in passing from a dense into a rarer medium, is immense; and the momentum of this steam must be very considerable. On the sudden and free communication effected between the cylinder and boiler of a Cornish engine, the steam in the cylinder receives an instantaneous action, proportionate, in amount, to the velocity of the entering steam; and this action, by the property of fluids, is transmitted to the surface of the piston. This action, thus transmitted to the piston, and due to the communication suddenly established between the highly elastic steam in the boiler, and the steam in the cylinder, may be likened, I conceive with great propriety, to the force of percussion; by which term I propose to distinguish it from the action of the steam's simple elastic force.*

It will accordingly be found, as I proceed in the investigation, and reveal

* The force which I have expressed by the term percussion will, perhaps, be rendered clearer to some readers by the use of a comparison. The pile-driving machine illustrates the action of steam when suddenly and fully let upon a piston, as it is in the Cornish engine. The monkey strikes the pile

the quantity of action derived from this unsuspected source, that the most economical of the three engines is the one in which this action has been most fully and dexterously applied. It will also distinctly appear that the degree of useful expansion mainly depends on the amount of percussive action realized, not on the degree of the steam's nominal expansion, as usually calculated from the period of the stroke at which the admission valve is closed.

Determination of the quantity of Percussive Action. The dynamic effect, or quantity of action, due to percussion, is discoverable, and assignable for each example. It may be measured by the length of stroke performed by its sole influence—by its separate value throughout the expansive portion of the stroke—or by its value throughout the entire stroke.

The mean elastic force of the steam, during its expansion in the cylinder, from the line of its equilibrium with the resistance, to the end of the stroke, was—

Per square inch on the piston. lbs.	
12·55	at Huel Towan. (App. 6.)
10·30	at Holmbush.
9·60	at Fowey Consols.

During, therefore, this usefully expansive portion of the stroke, the steam's simple elastic force, compared with the resistance, was in deficiency by the following amount, viz.—

Per square inch on the piston. lbs.		Expansive stroke. Inches.	
5·46	through	69·30	at Huel Towan. (App. 9.)
5·70	,,	76·73	at Holmbush.
5·65	,,	90·22	at Fowey Consols.

head with a force as much greater than that of its simple weight as is due to its velocity at the instant of impact.

The force resulting from the motion of fluids, as in the hydraulic ram, illustrates my meaning equally with the pile-driving machine.

I have adopted the term percussion, though usually applied only to solids, as the most appropriate and significant I can use; but, though assuming identity of character in the force, I am far from intending to convey the idea of equality in the effect derived from the motion either of solids, or fluids, and that of an æriform elastic fluid like steam.

It forms no part of my task to investigate the abstract question of the quantity of this species of force to be obtained from steam; my present purpose is confined to the determination of the effect attributable to it in the three engines subjected to analysis.

These sums represent the amount of aid given to the expanding steam by the discharge of the momentum originally impressed on the mass of pump rods, &c. by the steam's percussive action.

We have now the means of finding the space through which the pistons were carried by the sole influence of the percussive action; for, by the foregoing method of treating the subject, the elastic force of the unexpansive and expansive steam—the spaces through which these forces acted—and the deficiency of the expansive force to complete the stroke, are known. The influence of the percussive action, therefore, is producible in terms of the portion of the stroke performed by it; for the proportion of what I have termed the expansive stroke, really effected by the steam which entered the cylinder, is as the ratio between the whole pressure required to overcome the resistance, and the mean pressure of the expanded steam: and it results that the deficiency in the steam's expansive force to complete the stroke was equivalent to—

Inches of the stroke.	
21·01	at Huel Towan. (App. 10.)
27·33	at Holmbush.
33·43	at Fowey Consols.

The pistons were driven through these spaces by the force of percussive action alone, for the steam's simple elastic force was capable only of carrying the entire load through—

Inches of the stroke.		Total length of stroke. Inches.	
98·99	at Huel Towan, out of .	120.	(App. 10.)
71·67	at Holmbush, out of . .	109.	
90·57	at Fowey Consols, out of	124.	

This final result may appear startling, and I confess that when it flashed across my mind, as a truth, that some portion of the stroke must have been performed without any expenditure of steam, I was myself startled, and set about investigating the problem with great doubts of being able to detect, and assign the quantity of action which it seemed to me could only be attributed to the impact on the piston, on the sudden opening of the admission valve.

Conditions under which a Cornish engine works. But let us consider under what circumstances the engine is when steam is admitted on its piston. A complete stroke has been performed —the engine has been brought to rest by the resistance of a cushion of steam

imprisoned between the piston and cylinder cover—a vacuum is formed beneath the piston—the pressure of this cushion of steam, together with that of the column of water against the plungers, then sustains the entire weight which operated to perform the return stroke. In this state of things, a communication is suddenly and freely opened between the cylinder, and boiler, the elasticity of the steam in the latter being five or six times greater than in the former. The piston is free to move with a comparatively slight increase of insistent pressure, and must necessarily feel, for an instant, percussion; it is impelled by a blow inflicted upon it by the momentum of the entering steam. The piston, therefore, is started by this sudden action, and there is no equal force to follow, for the steam's further influx into the cylinder is not only retarded, but its force is diminished in intensity by its passage through the throttle-valve, and by other causes.*

Percussive action detected by the Indicator Diagram. Mr. Henwood's indicator diagram distinctly exhibits the action I have just explained. Had not this transcript of the piston's movements, and of the steam's elasticity, been taken at the same time that its consumption was ascertained, I might have failed to convince either myself or others of the conformity of this theory with truth. That the piston has received an almost instantaneous impulse, and greater than the force of the pursuing steam, is made evident by its retiring faster than the steam can follow with equal force. The diagram assures us that the piston has scarcely moved before the steam begins to dilate within the cylinder; it shews that a void is more quickly created by the piston's velocity, than the continually entering steam can fill up at an uniform density. Were not this the fact, the diagram would exhibit an uniform pressure of steam from the first instant of its admission till the instant of cutting it off; for it must be borne in mind that the admission valve remains wide open during that period, and that if the piston moved only in obedience to the simple elastic force of the steam, its velocity would be uniform during the entire interval of communication between the cylinder and boiler.

Mr. Henwood has given data which will assist in making some approxi-

* The throttle-valve is the *governor* of the engines under consideration. Its position is between the steam-valve and boiler. The steam-valve, once set, works for weeks and months without any alteration being made in its lift, or in the duration of its opening. The throttle-valve requires and receives continual adjustment; it is always open, but its aperture is so regulated as to *wire-draw* the steam more or less as the pressure rises or falls in the boiler. By this arrangement the steam-valve determines the quantity, and the throttle-valve the elasticity of the steam admitted on the piston. In other Cornish engines the throttle-valve is not used, and the engine is regulated by the lift, and duration of the opening of the steam-valve.

mation to the velocity of the steam's influx into the cylinder of the Huel Towan engine. The duration of the working stroke was 1·6 second; the steam's influx was stopped at about 0·22 of the stroke, which, on the supposition of an uniform rate of motion by the piston, was effected in about one-third of a second. In this time a mass of steam forming 76 cubic feet, and weighing 6·64 lbs., entered the cylinder. The area of the valve was 50·26 square inches, and that of the cylinder, deducting the piston-rod, 4988·08 square inches. These data give a mean velocity to the current of steam, through the valve, of 600 feet per second, or 400 miles per hour.

But the steam's initial velocity, on the opening of the valve, must have greatly exceeded this mean rate. The indicator diagram shews that, from the instant the piston had travelled 6 inches, or had made $\frac{1}{20}$th part of the stroke, the steam already within the cylinder, as well as the steam still entering it, underwent rapid expansion; proving that the piston moved faster than the steam continued to get into the cylinder, and maintain an elasticity within it equal to that it possessed at 6 inches of the stroke. The steam, in consequence, suffered expansion, as shewn by the diagram, during 19 out of 20 parts of the piston's course, though it was admitted through an unvarying aperture, during 4 out of 20 parts, and the piston's velocity must have diminished with the steam's attenuation* (*see* Plate).

Phenomena illustrative of percussive action.

Mr. Henwood's paper affords me another illustration of the truth of the theory I am attempting to develope. It is derived from his observation that, as the steam's pressure increased in the boilers, the temperature of the water discharged by the air-pump diminished. He remarks, " As the pressure of the steam in the boilers increased, the temperature of the hot well

* The steam's rapid expansion during its influx into the cylinder cannot have been caused by a diminishing elasticity in the boilers. The steam reservoir contained 700 cubic feet at a pressure of 64·1 lbs.; the quantity abstracted per stroke being 76 cubic feet at a mean pressure of 24·75 lbs. per square inch. Allowing for the difference in density, the quantity introduced into the cylinder amounted only to $\frac{1}{18}$th of the mass of steam in the boilers; whilst the variation in its elastic force in the cylinder, during admission, was $\frac{1}{5}$th. The boilers, also, contained 1080 cubic feet of water of the temperature of the steam, which would instantly supply the volume abstracted at a very slight diminution of elasticity.

On the supposition that the first six inches were performed in the mean time of the stroke, and whilst the valve was being opened by the cataract, that operation consumed about 0·080 second.

The piston's velocity during the working stroke was at the rate of 375 feet per minute. It would be curious and instructive to ascertain the periods of time in which equal increments of a working stroke are performed. This might be accomplished, and the steam's elasticity taken, simultaneously. Similar observations should be made during the return stroke, which in this case was effected at the rate of 100 feet per minute by the plungers.

declined, so that by observing the alteration in one, that of the other could be predicted with great certainty."

Now let us examine this fact, and its bearing on the subject. An increasing elasticity in the boiler would cause the engine to make a longer stroke, were the steam permitted to enter the cylinder at that increased force; but its elasticity is reduced by diminishing the aperture of the throttle, or governing valve. This constitutes the practical regulation of the engine's stroke, for the admission valve remains unaltered, and fully open, during a constant portion of the stroke. The quantity of water injected into the condenser was also constant during these observations; yet the phenomenon is presented of a diminished temperature communicated to that water by a cylinder full of steam, when the elasticity, and consequently the temperature of the steam within the boiler is the greatest!

The explanation is obvious. A less weight of water as steam suffices to perform the stroke, when the steam's elasticity increases in the boiler; for the greater the difference between the elastic force in the boiler, and that in the cylinder, at the commencement of the stroke, the greater will be the percussive action transmitted to the piston; consequently, steam of a less density will be required to complete the stroke. The regulation of the throttle-valve effects that object, and since a less weight of water as steam is admitted into the cylinder, less heat passes from the cylinder into the condenser.

During the observations recorded on the Huel Towan engine, the range of the steam's pressure in the boilers varied from $77\frac{1}{4}$ to $47\frac{1}{4}$ lbs., or 37 lbs. per square inch; and its temperature, consequently, from 311° to 279°, or 32°. The temperature of the water discharged by the air-pump varied, inversely, through a range of from 90° to $100\frac{1}{2}$°, difference $9\frac{1}{2}$°.* The steam's influx into the cylinder was intercepted at precisely the same portion of the stroke throughout the experiments, so that its volume, when cut off, and its subsequent expansion, were constant quantities. But, it is certain that the steam quitted the cylinder in a more attenuated state when its elasticity was greatest in the boiler, for a given volume of steam is seen to have communicated a less

* Henwood, page 55, Table 2. Careful observations on the temperature and quantity of water injected into, and discharged from the condenser of these engines, made concurrently with exact observations on the steam's elastic force in the boiler, and its force in the cylinder at the end of the working stroke, would elicit many highly useful and instructive facts.

amount of heat to a given volume of condensing water. Had the admission valve been closed earlier, as the steam's elastic force increased in the boiler, the phenomenon in question would have been attributed to the effect of a greater quantity of expansive action; but no greater nominal expansion was given. Be it observed, that the only physical change in the condition of the engine, during the experiments, was the variation in the steam's elastic force in the boiler; and the only mechanical change was that of the greater or less aperture given to the throttle-valve. Did not percussive action increase with the elasticity in the boiler, the throttle-valve would be so regulated as to administer steam of a constant force, and therefore, of a constant density, into the cylinder. But it is evident that an increased elasticity in the boiler necessitates, practically, as well as theoretically, a greater proportional contraction of the aperture; and thus it arises that steam of a gradually diminishing density exists in the cylinder, as its density and elastic force increase in the boiler.*

Other corroborative evidence of the truth of this theory might be adduced from the well-known fact in Cornwall, that the duty of an engine falls off, or more steam and fuel are required to perform a given effect, when, from the circumstance of leakiness, or deterioration in the boilers, it is found necessary to diminish the pressure within them; the steam being admitted during the same portion of the stroke, and, therefore, no change being made in the degree of nominal expansion.

Economy not dependent on the degree of the steam's nominal expansion.

Returning to the examples under review, it is found that the economy attained is inversely as the steam's terminal elasticity; or, what is the same thing, directly as its attenuation in the cylinder, at the end of the working stroke. This conclusion would be predicted from a perfect knowledge, or true theory of the steam's action; for a greater economy of steam in one engine over another, or in the same engine at different times, can arise only from having exhausted the steam admitted into the cylinder of a greater proportion of its absolute force, in one case, than in another. That such was the fact, in these three instances, is forcibly exemplified by placing the effect produced by equal weights of water, as steam, in juxta-position with the steam's elasticity at the end of the working stroke.

* This has reference only to what occurs in any given engine. It may happen from various causes that, of two engines, the one which has the greatest elastic force of steam in the boiler may realize the least amount of percussive action in the cylinder.—(*See* note, p. 285.)

Absolute effect in pounds raised 1 foot by 1 lb. of Steam. lbs.		Steam's elasticity at the end of the stroke per square inch on Piston. lbs.
135253	. . . .	7·30 at Huel Towan. (App. 11.)
196123	. . . .	4·66 at Holmbush.
210332	. . . .	3·95 at Fowey Consols.

The degree of what I have termed useful expansion is truly measured by the ratio which the absolute resistance bore to the steam's elasticity, on the termination of the working stroke, which was as follows:—

Ratio of the absolute resistance to the Steam's elasticity at the end of the stroke.

As 1 to 0·405 at Huel Towan. (App. 9.)
As 1 to 0·288 at Holmbush.
As 1 to 0·259 at Fowey Consols.

It thus distinctly appears that the steam virtually suffered the greatest expansion, or attenuation, in the engine which performed the greatest effect, and, hence, its superior economy. But the admission of steam is reported to have been intercepted at periods which assign the least nominal expansion to the most economical of the three engines, viz.—

At about $\frac{1}{5}$ or 0·22 of the stroke at Huel Towan.
,, $\frac{1}{6}$ or 0·166 ,, Holmbush.*
,, $\frac{1}{4}$ or 0·25 ,, Fowey Consols.*

* The capacity of the Holmbush cylinder above the piston at one-sixth of the stroke would be 20·178 cubic feet, exclusive of the space and passages, and, if filled with steam at 30 + 14·71, or 44·71 lbs. per square inch, assumed by Mr. Wicksteed as the pressure on the piston from the instant of opening to the instant of closing the steam-valve, the constituent water of that volume of steam would have been 2·06 lbs., representing the quantity expended per stroke. This sum, multiplied by 672, the number of strokes made by the engine, and divided by 94 lbs., the weight of coal consumed during his experiment, would give an evaporative product of 14·72 lbs. per pound of coal!

Mr. West states that the steam entered the cylinder of the Fowey Consols engine at 27 + 14·71, or 41·71 lbs. per square inch. Had the steam maintained this pressure in the cylinder throughout one-fourth of the stroke, its constituent water would have been 8·56 lbs., which, multiplied by 6287, the number of strokes, and divided by 2256, the number of pounds of coal burnt during the experiment, would give an evaporation of 23·8 lbs. of water by 1 lb. of coal!

Fortunately, Mr. West ascertained the real evaporation to be 10·50 lbs. per pound of coal, and, it being known that no instrument was employed to measure the steam's elasticity in the cylinder, in either of these experiments, but that it was only an estimation, doubt does not extend to the observed facts which remain unimpeached. The indicator would have shewn—as in the case of the Huel Towan —that whatever might have been the pressure of the steam on the instant of opening the steam-valve, its pressure in the cylinder, on closing it, would be very different. The indicator diagrams

The nominal amount of expansion suffered by the steam is, therefore, no criterion of economy, which mainly arises from the intensity of the percussive action, for, upon its intensity depends a large quantity of the expansive action which can be brought into play; and upon the quantity of the combined action of these two forces depends the economy realized, compared with the effect of steam used unexpansively throughout a stroke.

Phenomenon of the engine's voluntary retrograde motion at the end of the working stroke; its indication of percussive action.

I have stated that the proof of a force having operated, distinct from the steam's continuous action, did not altogether depend on the precise accuracy of the value assumed for the absolute resistance. I will now exemplify my meaning, by adducing additional evidence of the insufficiency of the steam's simple elastic force to perform the work of these engines, which will also throw light on the nature of the force which makes up the complement of power.

In reflecting on the phenomena which ought to attend a deficiency of the steam's simple elastic force, if such existed, it occurred to me that practical testimony to the fact might be obtained, by ascertaining whether the piston would return back on the completion of the working stroke, if the equilibrium valve were kept closed. The inference seemed to me inevitable that a return stroke would commence against the steam above the piston, if the complementary force had overcome a greater portion of the absolute resistance, during the working stroke, than was equivalent to engine and pit-work friction. In other words, if on the termination of the working stroke, the column of water, and the steam's pressure upon the piston, were jointly inferior to the weight of the pump-rods, the latter would preponderate, and a retrograde movement of the engine take place, until, by the steam's compression, an equipoise were established.

I thought it not unlikely that so good an observer as Mr. Henwood might have noticed whether the engine would so return against the steam. I accordingly requested him to inform me if he had done so, and if not, to make the experiment by keeping the equilibrium valve closed, and note what would happen. His reply is as follows:—" In order to see the engine return against the steam above the piston, I removed the tappet from the plug-rod, and kept

shew that no one can predict the steam's elastic force in the cylinder from a given elasticity in the boiler, it being very variable throughout the period of its admission. It is evident, also, that the whole power in operation cannot be deduced from the steam's mean elastic force previous to cutting it off, either by the law of Boyle, or any other theory of expansion.

the equilibrium valve closed, after the piston reached the bottom, for some short interval. This I repeatedly did during the experiments at Huel Towan, and the engine always *went out*, but I did not measure the extent of its motion."

We have here evidence of a positive kind, independent of all estimations and calculations, that the working stroke could not have been performed by the simple elastic force of the steam alone. It is manifest that in order to raise the mass of pump-rods—which is the steam's business—the power employed must exceed their weight, by the amount of friction inseparable from the motion of the plungers, rods, and engine; yet we see that when the mass has been raised through a certain space, it suddenly commences an opposite movement, and passes through some space of a return stroke.

This retrograde motion proves that a part of the force which assisted in raising the mass had disappeared, or become extinct; for, the remainder is not only insufficient to continue the piston's descent, but unequal to sustain the raised mass in its position, with the aid of the column of water. It is obvious that, on the slightest preponderance of the pump-rods, the plungers would instantly meet the column of water, and so much of the weight of the mass would be counterpoised, as is equivalent to the pressure of that column. The steam's force upon the piston at the end of the working stroke was therefore in deficit, by an amount as much greater than that of engine and pit-work friction, as was necessary to give preponderance to the pump-rods, or the engine would have remained stationary; unless an extinction of power to that amount, at least, had taken place, motion in the opposite direction could not have ensued.

The following remarks may tend to illustrate the character of the force which has been exerted, but which does not exist at the termination of the stroke.

It is certain that a very small (if any) portion of the steam which entered the cylinder could have been condensed during its action; for, the cylinder is surrounded with steam of the pressure of that in the boiler, and, consequently, of a temperature higher than that within the cylinder, at every portion of the stroke. No loss of steam, nor diminution of the full effect it was capable of producing, can, therefore, have been suffered.

The sudden relative change which occurred between the quantity of power and of resistance, when the piston reached the end of its course, must then have arisen from the using up, or exhaustion of some constituent portion of the entire power, possessing a nature distinct from the steam's simple elastic

force. It is manifest that this complementary force must have been of a transient description; that its effort was momentary, not continuous; and that its exertion must have taken place at the commencement, not at any subsequent period, of the stroke; for, at no subsequent period, could such a force have been called into play. The transient character is precisely that of a momentum originally communicated to the mass of the engine; and whence can it have been derived, but from the instantaneous action transmitted to the piston, on effecting the sudden communication between the steam in the cylinder, and that in the boiler?

This important fact of the preponderance of the pump-rods over the two opposing forces of the column of water, and of the steam's pressure on the piston is, also, demonstrable; for, we are in possession of the amounts of those forces in the Huel Towan engine, and can compare them with the force of steam in the cushion which was requisite to bring the return stroke to a termination, and to counterpoise the entire weight of the descending mass, with the aid of the column of water.

The two resistances against which the engine went out, when observed by Mr. Henwood, were—

Water load per square inch. lbs.		Steam's force above the piston, at end of stroke. lbs. per sq. inch.		Imperfect vacuum. lb. per sq. in.		Per square inch. lbs.
* 10·52	+	7·30	−	1·25	=	16·57

The pressure of steam in the cushion was 10·7 lbs. per square inch,† but there existed beneath the piston, from imperfect vacuum, an elasticity (assumed) of 1·25 lb., leaving a net force of 9·45 lbs. per square inch above the piston. This sum, added to the pressure of the column of water acting against the four plungers, forms a total of 19·97 lbs. per square inch, as the counterpoise of the mass of the pump-rods. It is evident that the same mass could not be sustained by a less weight, or 16·57 lbs. per square inch. The engine, therefore, on the exhaustion of that force which I have termed complementary to the steam within the cylinder, must necessarily retrograde. At the end of the working stroke an excess of weight over the opposing forces of the column of water, and of the steam in the cylinder, is thus proved to have existed in the pump-

* One of the five pumps worked by this engine was a lifting pump, and its load raised by the working stroke; so that in *going out* the engine was resisted only by the columns of water of four pumps. Henwood, p. 57.

† Deduced from the indicator diagram.

rods; and this preponderance generated the retrograde movement observed, and deduced as the natural consequence of a deficiency of steam to effect the working stroke.

The examination of this phenomenon thus exhibits a satisfactory accordance between analytical and synthetical results. It confirms, too, within very narrow limits, the accuracy of the data used in the investigation. It shews that the assumed absolute resistance of 18·01 lbs. per square inch is not exaggerated in the example of the Huel Towan, for, we find the engine retrograding, *i. e.*, the mass of pump-rods descending against two resistances ascertained to amount to 16·57 lbs. per square inch, and it has already been shewn that, in bringing back that mass during the working stroke, the steam must overcome engine and pit-work friction, and, in this case, the load of an additional pump, which, with the resistance from imperfect vacuum, and independent of friction, makes up 18·31 lbs. per square inch. It is thus demonstrated that the mean force of 14·85 lbs. per square inch, due to the exertion of the steam's simple elastic force throughout the stroke, was inadequate to balance the force opposed to it.*

Several facts of interest and consequence are disclosed by this last investigation.

* Since this paper was read before the Institution, I have requested Mr. West to ascertain whether, and to what extent, the Fowey Consols' engine would return against the steam; and he has informed me "That the piston will ascend 10 inches against the steam in the cylinder, before the equilibrium valve is allowed to open."

This fact affords data, with the quantities already found, for determining very nearly the weight of the mass of pump-rods, and the absolute resistance opposed to the steam in that engine.

The steam's elasticity above the piston, at the end of the working stroke, was 3·95 lbs., which, by the piston's return through 10 inches, would be compressed into 4·30 lbs. per square inch when the equipoise was established. Deducting 1·25 lb. per square inch for elasticity beneath the piston, the retrograde movement took place against the column of water amounting to 9·26 lbs., and against the steam's force in the cylinder amounting to 3·05 lbs., making 12·31 lbs. per square inch when the engine came to rest. This is the resistance opposed to the power by the weight of pump-rods only.

In raising this mass during the working stroke, the steam has to overcome the elasticity of 1·25 lb. beneath the piston, which, added to 12·31 lbs., makes an ascertained portion of the absolute resistance, amounting to 13·56 lbs. per square inch. Further, the steam has to overcome engine and pit-work friction; yet, its mean simple elastic force throughout the stroke was only 11·13 lbs. per square inch.

The excess of the weight of the pump-rods over the resistance of the column of water is shewn, in this case, to be equivalent to a pressure of 3·05 lbs. per square inch on the engine piston—representing the force necessary to balance water, engine, and pit-work friction. The two latter have again to be overcome by the steam during the working stroke, and estimating them to amount to 1·69 lb. out of the 3·05 lbs. per square inch, that sum added to 13·56 lbs. makes up the 15·25 lbs. per square inch, assumed in the previous calculations as the absolute resistance opposed to the steam.

Methods of ascertaining the absolute resistance, and its component portions.

By means of an indicator, or mercurial column placed on the cylinder cover, the following measures of resistance may be obtained.

1st. The absolute resistance during the working stroke. To find this quantity, in terms of pressure, it is only necessary to give so much steam above the piston, as to produce equilibration between its force and that opposed to it. When the piston acquires the slightest appreciable motion in descent, the counterpoise is complete. The value of imperfect vacuum must be ascertained, and deducted from the pressure above the piston.

2nd. By keeping the equilibrium valve closed, and allowing the engine to perform a voluntary retrograde movement, at the end of the working stroke, till it comes to rest by compressing the steam, the total weight of the pump-rods will be accurately denoted by the pressure of the column of water against the pumps, added to the pressure of steam upon the piston, minus the elasticity from imperfect vacuum beneath the piston.

3rd. The net pressure of the steam, last found, balances and measures the excess of the weight of pump-rods over the column of water. It counterpoises that portion of the entire weight which is requisite to overcome friction of all descriptions during the return stroke, and to deliver the water at the required velocity.

4th. The difference between the sums found by the 1st and 2nd propositions, is the value of engine and pit-work friction.

5th. The difference between the sums found by the 3rd and 4th propositions, is the joint value of the friction of the column of water, and of the weight necessary to displace it at the velocity of the return stroke.

The indicator, thus used as a pressure gauge, will unerringly furnish these important data, for the engine is at rest, and the steam quiescent when the observations are taken. The small space of time requisite to obtain them, cannot subject a mining engine to any inconvenience; and the absolute resistance being determined, together with the consumption of water as steam per stroke, the sufficiency, or insufficiency of the steam's mean simple elastic force throughout the stroke to overcome the resistance, may be readily determined on any engine.

Action of the cushion of steam.

The cushion, which is a quantity of steam recovered from the expiring stroke, and saved from annihilation in the condenser, is ingeniously used to break the shock in bringing the engine to a state of rest. It is also

a positive gain of power, as that steam gives out useful action in the next succeeding stroke, by expanding from its initial to the terminal elasticity in the cylinder. The quantity of action arising from this source, though small, is appreciable, but I am unable to separate it in all these instances, being ignorant of the exact elasticity of the recovered steam in the Holmbush and Fowey Consols engines. The consideration of this quantity is chiefly important as exhibiting the fact that, unlike the double-acting, the single engine loses no part of the full effect of the steam consumed, by uselessly filling the space between the piston, the cylinder-cover, and nozzles, as the cushion consists of steam which has already done its office; it is so much steam replaced after being used. The dynamic effect of the cushion, estimated distinct from that of the fresh steam introduced into the cylinder, in no case, probably, much exceeds one inch of the entire stroke performed by its sole influence. In the present analysis, its amount forms part of the effect attributed to the expansive steam.*

Economical results. The first of the two following tables exhibits the aliquot parts of the stroke performed by the several forces as analytically investigated, the

* The elastic force of the steam in the cushion, relatively to the force of the absolute resistance, depends chiefly on the period of effecting the vacuum beneath the piston. In the Huel Towan, the exhausting valve was opened at *d* (see plate) about 2 inches before the return stroke terminated. In some of the Cornish engines the exhaustion is not made till an instant or two before the steam valve is opened. In this latter case, the equilibrium valve is closed earlier, since, in order to bring the engine up, a denser steam is required above the piston by an amount equal to that which exists beneath it. Had the exhaustion been made subsequent, instead of previous to the termination of the return stroke in the Huel Towan, steam of 18 lbs. instead of 10·7 lbs. per square inch must have been compressed into the cushion; and, on making the vacuum, equilibration would very nearly have been established between the resistance, and the force in the cushion. Thus, more steam would have been recovered for use in the succeeding stroke.

When an engine is required to work fast, a heavier counterbalance is necessary to drive the water out of the pumps than when working slow. The engine then *goes out* with an accelerating velocity, and still higher steam is requisite to stop its motion. If this case occurs with the arrangement of exhausting after the engine has come to rest, it may happen that, on making the vacuum, the cushion of steam will preponderate in force over the mass to be raised, and by its exertion the piston will commence the working stroke previous to the admission of fresh steam. The quantity of action resulting from this source is then at a maximum.

Mr. Moyle has informed me that he has found, from repeated trials, an additional million of duty, or more, to be effected by opening the steam valve at the instant this rebound takes place, so as to catch the engine, as it were, *on the turn of the scale*, and when its *inertia* is overcome.

Theoretically, this should be the case, if the cushion of steam be alone considered; but the economy arising from it is mixed up with the attainment of the best vacuum, for which a certain time is necessary; and it is possible that the latter may be better accomplished by exhausting before the completion of the return stroke instead of later.

whole stroke being unity. The second shews the economy of each engine in terms of the weight of water as steam consumed per stroke, compared with the expenditure of water as steam, had it been applied unexpansively, or expansively, but not percussively.—

Aliquot parts of the Stroke performed			
By the Steam's percussive action.	By Steam equal to the resistance.	By expansive Steam.	Engines.
Whole stroke unity.	Whole stroke unity.	Whole stroke unity.	
0·175	0·423	0·402	Huel Towan. (App. 12.)
0·251	0·296	0·453	Holmbush.
0·270	0·272	0·458	Fowey Consols.

Consumption of Water as Steam per Stroke.			
Actually consumed.	If used unexpansively throughout the stroke.	If used expansively, but not percussively	Engines.
lbs.	lbs.	lbs.	
6·642	15·720	8·051	Huel Towan. (App. 13.)
1·434	4·843	2·181	Holmbush.
3·737	13·717	5·116	Fowey Consols.

In the general table annexed, I have introduced many other quantities brought to light in the course of the investigation. To it I must refer the inquirer, having deemed it more perspicuous to confine the foregoing account of the analysis strictly to the argument, and to the production of such facts and quantities as were indispensable for the development of the theory advanced in explanation of the steam's action. For the same reason I have excluded from the text all the formulæ and computations. The processes used will be found in the Appendix, for one engine, the Huel Towan, which will serve to guide the inquirer in his search after the corresponding quantities for the two other examples, and also to inform those who may be disposed to pursue a similar method of investigating the action of steam in other engines.

Of the Indicator as applied to Cornish Engines.

Near correspondence between the Indicator, and the method of the volumes.

The annexed indicator diagram from the Huel Towan engine has been carefully enlarged to three times the size of the figure described by Mr. Henwood, and appended to his paper. I have fortunately been enabled to compose a scale of pressures which had been mislaid or lost by him. He has supplied me with the original diagram, upon which the atmospheric line is traced; he had accurately ascertained the extreme elasticity of the steam in the cylinder, as denoted by the instrument, to be 27 lbs.; and, also, the elasticity at 0·22 of the stroke, which was 22 lbs. per square inch, as stated (page 61) in my last paper. I found the datum 22 lbs. to correspond so very nearly with equal divisions of the scale for pounds, between the atmospheric pressure (14·71 lbs.), and the extreme observation of 27 lbs., that there could be little doubt of accordance between the original, and this restored scale. Continuing these equal divisions downwards, below atmospheric pressure, I found the scale mark 7 lbs. as the steam's elastic force at C, on the termination of the working stroke.

The elasticity discovered by the ratio of the volumes of steam and water consumed, as shewn by the foregoing analysis, is 7·30 lbs. per square inch at the end of the stroke; a coincidence nearer than might have been expected.

A fourth point in the scale was thus established, admitting of very little doubt as to its near agreement with the original. This correspondence of pressures, at the period when the cylinder is filled with steam, obtained by methods instrumental and analytical, is highly satisfactory, not only as regards the reliance to be placed on the scale now restored to the diagram, and on the computation of the steam's mean force resulting from it, but still more, as confirming the datum of water consumed as steam, upon which the quantities brought to light by the analysis, mainly depend for their claim upon our belief. No doubt could be raised as to the contents of the cylinder when the piston was at the limit of its stroke, which gives the volume of steam consumed per stroke; but some doubt might not unreasonably have arisen as to the accuracy of the datum of evaporation. That evaporation was very large per unit of coal, but to bring the mean elastic force of the steam exerted throughout the stroke, to an equality with the resistance opposed to it, a much

greater evaporation would have been requisite; for much denser steam would have been required had not percussive action been brought into play, so as to aid, in the manner described, the steam's simple elastic force.*

I am now able to adduce the testimony of the diagram, which is a transcript of the steam's pressure upon the piston at every point of a stroke, that the steam's simple elastic force was insufficient to overcome the resistance opposed to it. The following are the pressures indicated at each 6 inches of the piston's descent in the cylinder:—

Inches of the Stroke.	Pressures. lbs. per square inch.	
6	27·0	
12	26·0	
18	24·4	
24	22·8	Steam's influx intercepted.
30	20·4	
36	17·4	
42	15·5	
48	14·2	
54	13·0	
60	12·1	
66	11·4	
72	10·6	
78	9·9	
84	9·4	
90	8·9	
96	8·4	
102	7·9	
108	7·6	
114	7·3	
120	7·0	
	20) 281·2	
	14·06 mean throughout the stroke.	

The steam's mean simple elastic force thus found is 14·06 lbs., and its force, as determined by the method of the volumes, 14·85 lbs. This difference

* Each pound of coal burnt must have evaporated 12¾ lbs. of water instead of 10½ lbs. to furnish steam of sufficient force to overcome the resistance.

of 0·79 lb. per square inch, in the results obtained by instrumental and analytical processes, is so trifling as not to affect the justness of the conclusions already arrived at. They serve to confirm each other. It would appear from the diagram, that the discrepancy between the mean force of the steam which entered the cylinder, and the resistance actually overcome, is somewhat greater than that deduced from the consumption of water as steam.

The indicator diagram has always been assumed to give a true measure of the resistance opposed to a rotative engine; the steam's force, thence deduced, being considered as truly equipoising the resistance. This may be a correct assumption, both for unexpansive and expansive double-acting rotative engines, as generally constructed, though I know of no instance in which the calculated power of the steam has been brought into comparison with an actually ascertained effect of such engines. I have shewn (page 280) under what circumstances this instrument may be applied to denote truly both the absolute resistance, and its constituent quantities; but it will be apparent, that though its diagram may give a nearly exact measure of the steam's simple elastic force in a Cornish single engine, it has also afforded a most fallacious measure of the absolute resistance overcome.*

* This section has been written since the paper was read before the Institution. I had not, then, received from Mr. Henwood the original diagram from the Huel Towan engine with the atmospheric line upon it.

I have also annexed two diagrams from the East Crinnis engine which are very instructive (Henwood, figs. viii. & ix). They were taken by the same indicator as the Huel Towan, and Mr. Henwood having also supplied me with the originals, bearing the atmospheric line, I have been enabled to enlarge and apply to them the recovered scale, and to compute the mean pressure upon the piston for each example.

It results from each diagram, that 14·05 lbs. per square inch was the steam's mean elastic force throughout the stroke, but, at the end of the stroke its elasticity was 7·6 lbs. in fig. 8, and 8·5 lbs. in fig. 9. Now, the only variation in the circumstances of the engine at the two periods (as noted by Mr. Henwood, and recorded on his diagrams) was the steam's elasticity in the boiler, which, in the first case amounted to 36·8 lbs., and in the second case to 26·3 lbs., being a difference of 10·5 lbs. per square inch. In both cases the steam valve remained open during the same period of the stroke; the nominal expansion, therefore, was identical in both cases; nevertheless, it is seen that a greater expansion of the steam took place in the cylinder, when its elasticity was greatest in the boiler; for, at the termination of the stroke, it was more attenuated in the first case by nearly 1 lb. per square inch, than in the second case. A less weight of water as steam had actually entered the cylinder in the first case than in the second, though the steam in the boiler was denser, and the admission valve open during the same period. An ocular inspection of the two diagrams suffices to shew that the initial velocity of the piston was greater in the first case than in the second; and, that the steam underwent rapid expansion from nearly the instant of the piston's movement, to the end of the stroke. In the second case, however, the piston passed through 9 inches of the stroke (10 ft. 3 in.) before expansion commenced.

Conclusion.

An accurate knowledge of the forces employed, and of their action, constitutes what is termed the theory of the engine, with which the practical engineer should be as intimately acquainted, as with its materials and mechanical structure. It is only by a clear perception of the former, that he can so arrange the latter, as to obtain the maximum effect from the power employed. The Cornish engineers have, unconsciously, applied the percussive action, as well as the elastic force of steam, and we have an instance in the Fowey Consols engine of $\frac{27}{100}$ths, or more than a quarter of the stroke being performed by percussive action alone; in other words, more than one-fourth of the effect was obtained without any cost of steam. If a method could be devised of withdrawing the steam again from the cylinder, after inflicting the blow upon the piston, these blows might be repeated by the same steam *ad infinitum;* but, since steam must necessarily accompany its percussive effort, the object of the constructor must be to appropriate the greatest possible quantity of this force, with the consumption of the least possible quantity of the steam's material ingredient.

Neither diagram marks the period of intercepting the steam. In fig. 8, there is no trace of it; in fig. 9 it would seem, from a superficial view, that the steam valve was closed where the upper horizontal line terminates, and expansion commenced. But such was not the fact, as that line of nearly equal pressure ceased at about 9 inches, *i. e.*, at about $\frac{1}{14}$th of the stroke, and the steam was admitted during about $\frac{1}{5}$th part.

The water load (11·4 lbs. per square inch on the piston) and other circumstances of this engine were so nearly similar to those of the Huel Towan, at the time of the experiments, that the deficiency of the steam's simple elastic force to overcome the resistance must at least have equalled the amount previously found for the Huel Towan engine.

The computation of these two diagrams verifies Mr. Henwood's observation that the temperature of a given volume of condensing water, when discharged, is inversely as the steam's elasticity in the boiler. It is manifest that a given volume of steam having an elasticity of 7·6 lbs. per square inch, contains less heat than the same volume at 8·5 lbs. per square inch. It justifies the notorious fact, and common belief in Cornwall, that more steam and fuel are consumed by the same engine as the pressure of steam falls in the boilers; and it confirms the deductions previously drawn from the varying temperature of the condensing water, (see page 273).

Similar facts are elicited from the computation of the diagrams of the Binner Downs engine (Henwood, figs. v. & vi.) In the first case the volume of steam in the cylinder, at the end of the working stroke, was 6·4 lbs., in the second case 7·4 lbs., being a difference of 1 lb. per square inch. The steam in these boilers varied in elasticity 16·78 lbs. per square inch, which thus produced an economy of about $\frac{1}{7}$th in favour of the higher steam, no change being made in the duration of the steam's admission.

The theory now submitted, rests upon facts; it is based on ascertained, not on hypothetical quantities; nor is it inconsistent with the theory of steam, which has led to doubt, and even to denial of the effects reported to be performed by Cornish engines.

The author hopes that conflicting opinions on this disputed subject will be much reconciled by the analysis of the data now presented, and that the disbelievers of facts asserted by practical men, will become believers, when they find their own doctrine of steam not irreconcileable with effects equally well established, though that doctrine, *per se*, be insufficient to account for them.

The multiplication of well-conducted experiments, to which the author hopes this investigation may lead, cannot fail to establish, or refute the theory he has ventured to lay before the Institution. His sole object being the discovery of truth, he submits these labours and opinions to that rigid examination, which so many of its members are competent to give, with the confident feeling that, whether the theory be substantiated, or disproved, our knowledge of the action of steam in the engine will be increased, and the economy of other classes of engines promoted by the inquiry.

JOSIAH PARKES.

12, Great College Street,
Westminster, June 1840.

APPENDIX.

Calculations for the Huel Towan Engine.

1. Required, the steam's elasticity in the cylinder at the end of the working stroke, from the volumes of steam and water consumed.

1st. Find the volume of water introduced into the cylinder per stroke.

$\overset{\text{Cub. ft.}}{847\cdot5}$ total quantity evaporated from the temperature $93\cdot8^\circ$ (Henwood).
$7\cdot5$ deducted for dilatation from 60°, and for impurities.

$840\cdot0$ total consumption.

$$\overset{\text{Cub. ft.}}{840} \div \overset{\text{Strokes.}}{7881} = \overset{\text{Cub. ft.}}{0\cdot1065}$$ water in steam entering the cylinder each stroke.

2nd. Find the volume of water existing in the cushion of steam, recovered.

$\overset{\text{lbs. per sq. in.}}{10\cdot7}$ steam's elasticity in cushion (Indicator diagram).
$\overset{\text{Cub. ft.}}{9\cdot176}$ volume of steam forming the cushion. (Henwood.)

The ratio which that volume of steam at $10\cdot7$ lbs. pressure bears to the volume of water from which it was generated, is 2365.—(*Vide* Table by M. de Pambour).

Then, $\overset{\text{Cub. ft. steam.}}{9\cdot176} \div \overset{\text{Ratio of steam to water.}}{2365} = \overset{\text{Cub. ft.}}{0\cdot0038}$ the constituent water in the cushion of steam at $\overset{\text{lbs.}}{10\cdot7}$ pressure.

And, $\overset{\text{Cub. ft.}}{0\cdot1065} + \overset{\text{Cub. ft.}}{0\cdot0038} = \overset{\text{Cub. ft.}}{0\cdot1103}$ total volume of water existing in the cylinder.

3rd. Find the volume of steam in the cylinder.

$\overset{\text{Contents of cushion. Cub. ft.}}{9\cdot176} + \overset{\text{Described by the piston per stroke. Cub. ft.}}{346\cdot394} = \overset{\text{Cub. ft.}}{355\cdot570}$ total volume of steam at the end of the stroke.

And $\overset{\text{Steam. Cub. ft.}}{355\cdot570} \div \overset{\text{Water. Cub. ft.}}{0\cdot1103} = 3223$ ratio of the volumes, denoting the steam's elasticity at the end of the working stroke to be $7\cdot30$ lbs. per square inch.

2. Required, the portion of the stroke performed by steam equal in pressure to the resistance.

Resistance estimated at $\overset{\text{lbs.}}{18\cdot01}$ per square inch against the engine piston.

1st. The entering steam has to raise the elasticity of the cushion from $10\cdot7$ lbs. to $18\cdot01$ lbs. which will require $0\cdot0027$ cubic feet of the water as steam introduced into the cylinder; found as follows. The ratio for the volumes at $18\cdot01$ lbs. is 1410; and $\overset{\text{Vol. of cushion. Cub. ft.}}{9\cdot176} \div \overset{\text{Ratio.}}{1410} = \overset{\text{Vol. of water. Cub. ft.}}{0\cdot0065}$ which

would be required, had the space above the piston been void; but, as it was already occupied by steam of 10·7 lbs. pressure, the difference only between the constituent water of the two steams is absorbed in elevating the cushion to the pressure of the resistance. Thus $\overset{\text{Cub. ft.}}{0\cdot 0065} - \overset{\text{Cub. ft.}}{0\cdot 0038} = \overset{\text{Cub. ft.}}{0\cdot 0027}$ water absorbed in the cushion.

2nd. $\overset{\substack{\text{Water introduced}\\ \text{into the cylinder.}\\ \text{Cub. ft.}}}{0\cdot 1065} - \overset{\substack{\text{Water absorbed}\\ \text{by cushion.}\\ \text{Cub. ft.}}}{0\cdot 0027} = \overset{\text{Cub. ft.}}{0\cdot 1038}$, volume of water in steam actually operating to urge the piston with an uniform force of 18·01 lbs. per square inch.

3rd. The ratio of the volumes of steam and water for 18·01 lbs. pressure is 1410.

4th. $\overset{\text{Ratio.}}{1410} \times \overset{\substack{\text{Water.}\\ \text{Cub. ft.}}}{0\cdot 1038} = \overset{\text{Cub. ft.}}{146\cdot 358}$, the volume of steam of 18·01 lbs. pressure generated from the volume of water.

5th. The capacity of the cylinder for 1 foot of the stroke is 34·6394 cubic feet.

6th. $\overset{\substack{\text{Vol. of steam.}\\ \text{Cub. ft.}}}{146\cdot 358} \div \overset{\text{Cub. ft.}}{34\cdot 6394} = \overset{\text{ft.}}{4\cdot 225}$, the portion of the stroke performed by steam equal in pressure to the resistance.

Obs. During this, which I have termed the *unexpansive*, portion of the stroke, the cushion robbed the entering steam of a small quantity of its power, but restored the whole of it during the subsequent *expansive* portion.

Whether it be considered that the steam entered the cylinder gradually at the pressure of the resistance, or, as it actually did, at a higher pressure, the whole of the steam was in the cylinder, and its force equipoised the resistance when the piston had descended 4·225 feet.

3. Required, the portion of the stroke performed during the steam's expansion below the pressure of the resistance.

ft.	
10·000	total length of stroke.
4·225	performed by steam equal to the resistance.
5·775	performed by steam expanding below the resistance.

4. Required, the absolute weight to be raised 1 foot.

1st. $\overset{\substack{\text{Area of piston.}\\ \text{Sq. in.}}}{4988\cdot 08} \times \overset{\substack{\text{Resistance.}\\ \text{lbs.}}}{18\cdot 01} = \overset{\text{lbs.}}{89835\cdot 3}$ resistance against the piston throughout the stroke.

2nd. $\overset{\text{lbs.}}{89835\cdot 3} \times \overset{\substack{\text{Stroke.}\\ \text{ft.}}}{10} = \overset{\text{lbs.}}{898353\cdot 0}$ to be raised 1 foot.

5. Required, the weight raised 1 foot by the elastic force of steam not less than the resistance.

$\overset{\substack{\text{Area of piston.}\\ \text{Sq. in.}}}{4988\cdot 08} \times \overset{\substack{\text{Resistance.}\\ \text{lbs.}}}{18\cdot 01} \times \overset{\text{ft.}}{4\cdot 225} = \overset{\text{lbs.}}{379554\cdot}$ raised 1 foot.

6. Required, the weight raised 1 foot by the elastic force of steam less than the resistance; that is, during its expansion below the pressure of the resistance.

1st. $\overset{\text{lbs.}}{18{\cdot}01} + \overset{\substack{\text{Steam's elasticity,}\\ \text{end of stroke.}\\ \text{lbs.}}}{7{\cdot}3} \div 2 = \overset{\text{lbs.}}{12{\cdot}55}$, the steam's mean force during expansion.

2nd. $\overset{\substack{\text{Area of piston.}\\ \text{Sq. in.}}}{4988{\cdot}08} \times \overset{\text{lbs.}}{12{\cdot}55} \times \overset{\text{ft.}}{5{\cdot}775} = \overset{\text{lbs.}}{361517}$ raised 1 foot.

7. Required, the total weight raised 1 foot by the steam's simple elastic force.

Raised 1 foot. lbs.	
379554	by steam not less than the resistance.
361517	by steam expanding below the resistance.
741071	total effect of the steam.

8. Required, the steam's mean pressure on the piston throughout the stroke.

1st. $\overset{\substack{\text{Raised 1 ft.}\\ \text{lbs.}}}{741071} \div \overset{\substack{\text{Length of}\\ \text{stroke.}\\ \text{ft.}}}{10} = \overset{\text{lbs.}}{74107{\cdot}1}$ mean load of steam on the piston.

2nd. $\overset{\substack{\text{Load on piston.}\\ \text{lbs.}}}{74107{\cdot}1} \div \overset{\substack{\text{Area of piston.}\\ \text{Sq. in.}}}{4988{\cdot}08} = \overset{\substack{\text{Per sq. in.}\\ \text{lbs.}}}{14{\cdot}85}$ mean pressure of steam throughout the stroke.

9. Comparison between the resistance overcome, and the steam's simple elastic force.

1st. $\overset{\substack{\text{Resistance.}\\ \text{lbs. per sq. in.}}}{18{\cdot}01} - \overset{\substack{\text{Steam's mean force}\\ \text{throughout}\\ \text{stroke.}\\ \text{lbs. per sq. in.}}}{14{\cdot}85} = \overset{\substack{\text{Per sq. in.}\\ \text{lbs.}}}{3{\cdot}16}$ difference, being the steam's deficiency throughout the stroke.

2nd. $18{\cdot}01 - \overset{\substack{\text{Steam's mean force}\\ \text{during expansion.}\\ \text{lbs. per sq. in.}}}{12{\cdot}55} = 5{\cdot}46$ difference, being the steam's deficiency during its expansion.

3rd. $18{\cdot}01 - \overset{\substack{\text{Steam's force at the}\\ \text{end of stroke.}\\ \text{lbs. per sq. in.}}}{7{\cdot}30} = 10{\cdot}71$ difference, being the steam's deficiency at the end of the stroke.

4th. As $\overset{\text{lbs.}}{18{\cdot}01} : 1 :: \overset{\text{lbs.}}{7{\cdot}03} : 0{\cdot}405$, being the ratio between the absolute resistance and the steam's elasticity at the end of the working stroke.

10. Required, the portion of the stroke which the steam's simple elastic force was insufficient to perform.

1st. It has been found that during $5{\cdot}775$ feet (3), or $69{\cdot}3$ inches, the steam's elasticity was less than the resistance, and that, throughout that space, its mean force was only $12{\cdot}55$ lbs. per square

inch. The space, then, through which the expanding steam could have overcome a force equal to the absolute resistance will be inversely as those forces.

$$\therefore \overset{\text{lbs.}}{18\cdot01} : \overset{\text{Inches.}}{69\cdot3} :: \overset{\text{lbs.}}{12\cdot55} : \overset{\text{Inches.}}{48\cdot29}$$

and $\overset{\text{Inches.}}{69\cdot3} - \overset{\text{Inches.}}{48\cdot29} = \overset{\text{Inches.}}{21\cdot01}$ the portion of the stroke equivalent to the steam's deficiency of power.

2nd. The same is found by the relation which the steam's mean force throughout the whole stroke bore to the force requisite to counterpoise the resistance; thus,

$$\text{As } \overset{\substack{\text{Resistance.}\\ \text{lbs.}}}{18\cdot01} : \overset{\substack{\text{Total stroke.}\\ \text{Inches.}}}{120} :: \overset{\substack{\text{Steam's mean}\\ \text{force.}\\ \text{lbs.}}}{14\cdot86} : \overset{\text{Inches.}}{98\cdot94}$$

and $\overset{\text{Inches.}}{120} - \overset{\text{Inches.}}{98\cdot94} = \overset{\text{Inches.}}{21\cdot06}$ the steam's deficiency of power in terms of the stroke.

Obs. It has been found (2) that when the piston had passed through 50·7 inches, the steam's elasticity and the resistance were in equilibrio. Motion would then have ceased, but for the momentum transferred to the mass of pump-rods by the excess of the steam's force over 18·01 lbs. between the instant of its admission into the cylinder, and the instant when the piston had descended 50·7 inches. It was the discharge of this momentum which assisted the steam, during its expansion below the elasticity of 18·01 lbs., to drive the piston through the additional space of 48·29 inches; but it was unable to complete the whole stroke by 21·01 inches. The precise value of this momentum, or, what is the same thing, the value of the excess of force over the resistance during 50·7 inches of the stroke, is determinable as follows:—

The volume of steam in the cylinder when the piston had descended 98·99 inches would be 294·951 cubic feet, and its ratio to the volume of water 2770, denoting the elasticity to be 8·9 lbs. per square inch. The steam's mean force between 50·7 inches and 98·99 inches—that is, through 48·29 inches, the expansive stroke—would thus be $\overset{\text{lbs.}}{18\cdot01} + \overset{\text{lbs.}}{8\cdot9} \div 2 = 13\cdot45$ lbs. per square inch; and $\overset{\text{lbs.}}{18\cdot01} - \overset{\text{lbs.}}{13\cdot45} = \overset{\text{lbs.}}{4\cdot56}$ per square inch; being the value of the momentum derived from the steam's excess over the resistance during 50·7 inches, and discharged during the remaining 48·29 inches of the stroke which the steam was capable of performing.

Now, it appears by the Indicator diagram that the maximum elasticity of the steam was 27 lbs., and that its mean elasticity between the instant of the commencement of the piston's motion, and the instant of the steam's falling to 18 lbs., was about 22·50 lbs. per square inch; shewing that a quantity of momentum had been transferred to the mass, equal to the exertion of a force of about 4·50 lbs. per square inch, through 50·7 inches of the stroke, over and above the pressure of the resistance. More than this amount could not be restored during the steam's expansion below the pressure of the resistance, and it is accordingly found that the whole of it was discharged when the piston had attained about 99 inches of the stroke, for it is seen that the exertion of a force equal to 4·56 lbs. per square inch was required through 48·29 inches to enable the attenuating steam to carry the load through that space.

The correctness of the analytical process is thus confirmed by the evidence of the indicator diagram, and it is demonstrated that the engine would have come to rest at 99 inches of the actual stroke, but for the steam's initial percussive action, which transmitted to the mass a quantity of momentum

equivalent, with the additional expansion, to the exertion of 18 lbs. per square inch on the piston through 21 inches, and enabled it to complete the stroke.

The values of the momenta derived from these two distinct sources, viz., first, from the excess of the steam's simple elastic force over the resistance, during a portion of the stroke; and, secondly, from the steam's percussive action, are thus separable and determinable.—(*See* Diagram of the steam's action.)

11. Required, the absolute effect of 1 lb. of water as steam actually consumed, in pounds raised 1 foot.

1st. Find the weight of water consumed per stroke.

Total Water. Cub. ft.		Temp. 60°. lbs. per cub. ft.		No. of Strokes.		Water as steam. lbs.	
840	×	62·3206	÷	7881	=	6·642	consumed per stroke.

	Absolute effect. lbs. raised 1 ft.		lbs.		lbs.	
2nd.	898353·208	÷	6·642	=	135253	raised 1 foot by 1 lb. of water as steam.

12. Required, the aliquot parts of the stroke performed by the several forces as analytically investigated; the total length of stroke being unity.

	Stroke. Inches.				Inches.		Parts of stroke.	
As	120	:	1	::	21·01	:	0·175	performed by the steam's percussive action.
	120	:	1	::	50·70	:	0·423	performed by steam equal to the resistance.
	120	:	1	::	48·29	:	0·402	performed by the steam's expansive action.
					120·00		1·000	

13. Required, the consumption of water as steam, if used unexpansively throughout the stroke; and, if used expansively, but not percussively.

1st. It has been found that, if admitted gradually at the pressure of the resistance, the whole of the steam would have entered the cylinder when the piston had passed through 50·7 inches. To continue motion to the end of the stroke by the same gradual admission, the consumption of steam would be proportional to the length of stroke;

	Inches.		Water as steam. lbs.		Inches.		Water as steam. lbs.	
∴	50·7	:	6·642	::	120	:	15·720	consumption required had the steam been used unexpansively throughout the stroke.

2nd. It has been found that the steam's simple elastic force, unaided by percussive action, would have urged the piston through 98·99 inches;

	Inches.		Water as steam. lbs.		Inches.		Water as steam. lbs.	
∴	98·99	:	6·642	::	120	:	8·051	consumption required had the steam been used expansively, but not percussively.

REMARKS.

The reduction of the other quantities contained in the Table is too simple to need illustration.

It is important that the cubic contents of the cushion of steam, and its elasticity, previous to the admission of fresh steam, should be ascertained in every case, to ensure perfect accuracy in the results obtained by the method of the volumes. In the instance of the Huel Towan, I have retained the capacity of the space above the piston originally assigned by Mr. Henwood, as it differs but little from measurements subsequently given me by Captain Samuel Grose, and Mr. Wm. West.

The contents of the cushion set down in the Table, and used in the calculations for the Holmbush and Fowey Consols engines, were furnished by Mr. West. The steam's elasticity is assumed, in both instances, as 10 lbs. per square inch; which, whether or not positively exact, will make but an insignificant difference in the quantities found for those engines.

DIAGRAM OF THE STEAM'S ACTION.

The following diagram exhibits the portions of the stroke respectively performed by the several forces.

The space *a* represents that portion through which the steam acted, until, by its expansion, it coincided in pressure with the resistance.

The space *b* is that through which the piston continued to be urged by the joint forces of the still expanding steam, and of the momentum transferred to the engine during the passage of the piston through the space *a*, and due to the temporary excess of the steam's force over the resistance.

The space *c* is that accomplished by the steam's initial percussive action. The intrinsic value of this force was equal to about 10 lbs. per square inch through 21 inches; or, to 1·75 lb. per square inch through 120 inches. But, it also enabled the steam to expand from about 9 lbs. to 7 lbs. per square inch, thus extracting from that source an action equivalent to 8 lbs. through 21 inches, or, to 1·40 lb. per square inch through 120 inches. And 1·75 lb. + 1·40 lb. = 3·15 lbs. per square inch, found to be the steam's deficiency of power throughout the stroke (*see* p. 266).

HUEL TOWAN CYLINDER.

Diameter 80 inches.

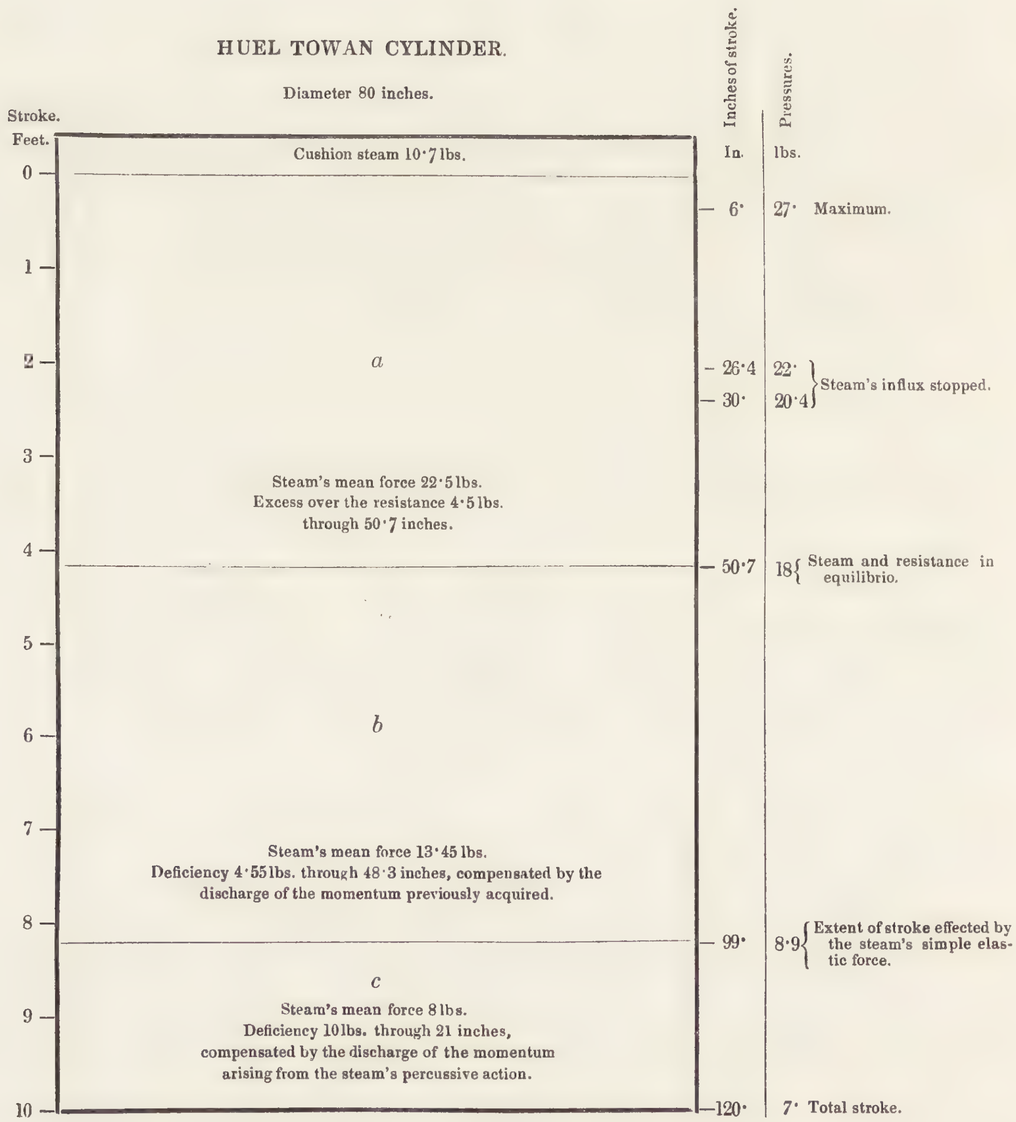

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TABLE.

ENGINES.	Diameter of engine cylinder.	Length of stroke.	Length of stroke in pumps.	Total height of lifts.	Load of water on pumps.	Area of engine piston, (piston rod deducted.)	Load of water on engine piston.	Resistance against the Engine. From water load.	Resistance against the Engine. From imperfect vacuum.	Resistance against the Engine. From frictions.
	Inches.	Inches.	Inches.	Feet.	lbs.	Sq. in.	lbs.	lbs. per sq. in. on piston.	lbs. per sq. in. on piston.	lbs. per sq. in. on piston.
Huel Towan . .	80	120	96	899·07	68666·44	4988·08	54933·12	11·01	1·25	5·75
Holmbush . .	50	109	97	535·50	21706·00	1935·22	19316·34	9·98	1·25	4·77
Fowey Consols .	80	124	111	789·00	51626·36	4988·08	46213·91	9·26	1·25	4·74

	Absolute resistance.	No. of strokes made by the engine during the experiment.	Water in steam introduced into the cylinder. (corrected for temperature)	Water in steam recovered, forming the cushion.	Total water in steam operating during the experiment.	Volume of water in steam introduced into the cylinder per stroke.	Volume of water in steam existing in the cushion per stroke.	Total volume of water in steam operating to perform a stroke.
	lbs. per sq. in. on piston.	Strokes.	Cubic feet.	Cubic feet.	Cubic feet.	Cubic feet.	Cubic feet.	Cubic feet.
Huel Towan . .	18·01	7881	840·000	29·947	869·947	0·1065	0·0038	0·1103
Holmbush . .	16·00	672	15·700	1·227	16·927	0·0230	0·0018	0·0248
Fowey Consols .	15·25	6287	377·000	25·942	402·942	0·0599	0·0038	0·0637

	Volume of steam filling the cylinder per stroke.	Volume of steam recovered, and forming the cushion, per stroke.	Total volume of steam operating to perform a stroke.	Ratio of the volumes of steam and water at the end of a stroke.	Pressure of steam on the piston at the end of a stroke.	Mean pressure of steam during its expansion below the pressure of the resistance.	Mean pressure of steam throughout the stroke.	Difference between the steam's mean pressure during expansion and the resistance.
	Cubic feet.	Cubic feet.	Cubic feet.	Ratio.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.	lbs. per sq. in.
Huel Towan . .	346·394	9·176	355·570	3223	7·30	12·55	14·85	5·46
Holmbush . .	121·071	4·500	125·590	5064	4·60	10·30	11·47	5·70
Fowey Consols .	357·820	10·380	368·200	5780	3·95	9·60	11·13	5·65

	Difference between the steam's pressure and the resistance at the end of a stroke.	Difference between the steam's mean pressure and the resistance throughout a stroke.	Ratio of the pressure of the resistance to the steam's pressure at the end of a stroke.	Mean pressure of steam in the boilers during the experiment.	Portion of the stroke performed by steam equal in pressure to the resistance.	Portion of the stroke through which the steam expanded below the pressure of the resistance.	Portion of the stroke performed by the steam's percussive action.	Portion of the stroke performed by the steam's simple elastic force.
	lbs. per sq. in.	lbs. per sq. in.	Ratio.	lbs. per sq. in.	Inches.	Inches.	Inches.	Inches.
Huel Towan .	10·71	3·16	1 to 0·405	64·11	50·700	69·300	21·010	98·990
Holmbush . .	11·40	4·53	1 to 0·288	54·71	32·268	76·732	27·336	71·664
Fowey Consols .	11·30	4·12	1 to 0·259	55·46	33·780	90·220	33·437	90·573

	Aliquot parts of the stroke performed. By the steam's percussive action.	Aliquot parts of the stroke performed. By the action of steam equal to the resistance.	Aliquot parts of the stroke performed. By the steam's expansive action below the resistance.	Weight of water in steam actually consumed per stroke.	Consumption of water as steam under other conditions. If used unexpansively throughout a stroke.	Consumption of water as steam under other conditions. If used expansively but not percussively.	Absolute resistance overcome, in terms of weight raised throughout a stroke.	Mean force exerted by the steam, in terms of weight raised by it throughout a stroke.
	Stroke, unity.	Stroke, unity.	Stroke, unity.	lbs.	lbs.	lbs.	Tons.	Tons.
Huel Towan . .	0·175	0·423	0·402	6·642	15·720	8·051	40·10	33·08
Holmbush . .	0·251	0·296	0·453	1·434	4·843	2·181	13·82	10·35
Fowey Consols .	0·270	0·272	0·458	3·737	13·717	5·116	33·96	24·80

	Steam's deficiency to overcome the resistance, in terms of weight to be raised throughout a stroke.	Absolute resistance overcome, in terms of weight raised one foot.	Absolute force exerted by the steam, in terms of weight raised by it one foot.	Steam's deficiency to overcome the resistance, in terms of weight to be raised one foot.	Absolute effect of 1 lb. of steam actually consumed, in terms of weight raised one foot.	Duty, or realized effect of 1 lb. of steam actually consumed, in terms of weight raised one foot.	Absolute effect of a bushel of coal (94 lbs.), in terms of weight raised one foot.	Duty, or realized effect of a bushel of coal (94 lbs.), in terms of weight raised one foot.
	Tons.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.	lbs.
Huel Towan .	7·02	898,353	741,071	157,282	135,253	82,705	132,930,526	81,389,900
Holmbush . .	3·47	281,241	210,711	70,530	196,123	122,350	200,576,166	117,906,992
Fowey Consols .	9·16	786,012	574,135	211,877	210,332	127,798	219,531,501	125,095,713

JUNE, 1840. J. P.

Back of
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XI.—*On Setting-out Railway Curves.*

By CHARLES BOURNS, Assoc. Inst. C.E.

Read May 5th, 1840.

Having been engaged in ranging the line of the Taff Vale Railway, which from the nature of the country presented circumstances of unusual difficulty, rendering it necessary to use curves constantly, and to vary their radii and flexure very frequently, my attention was particularly drawn to the principles upon which the practice of setting-out a line was founded, so as to preserve a proper continuity of curvature.

Various methods have been hitherto proposed, none of which appeared to me to be generally practicable. This consideration, and the necessity for facilitating the labours of the field, induced me to investigate the subject; and, with the assistance of my friend Mr. Samuel Downing, I have been enabled to arrive at several results which are, I trust, not unworthy the attention of the profession.

It is not possible in practice to have a line of railway straight throughout, nor of one continuous degree of curvature; but it will consist of a system of curves and straight lines; the curves being not uncommonly of contrary flexure, and of different radii.

The cases of most frequent occurrence will be those of passing from a straight line into a curve, or from a curve into a straight line; but it is also sometimes necessary to pass from one curve to another of different radius, or through a point requiring a change of flexure. In all these cases the connexion must be tangential; that is, a straight line, or a curve, must be a tangent to the succeeding curve or straight line, at the point of junction. The ranging of lines on this principle may be made to depend on a construction of simple geometry; whence also may be determined the offsets which are to be measured. So that the whole practice of ranging a line will be performed with a chain, an offset-staff, and a few ranging poles. The following propositions will point out the manner in which this is to be effected.

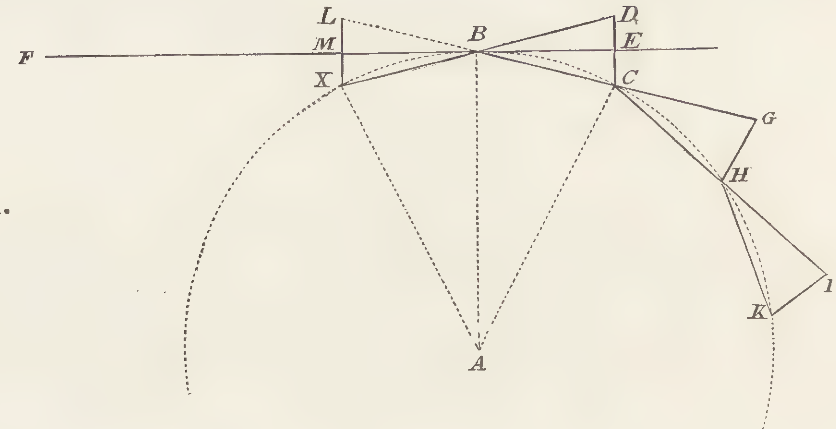


Fig. 1.

PROPOSITION I.

" To set out a curve of given radius."

In the accompanying figure let A be the centre of the circle, a segment of which is to be set out; $F\ E$ a tangent at any point B; $B\ X$, $B\ C$ equal chords; let $B\ D$ be taken equal to $B\ X$, and join D and C, by the line cutting the tangent in E.

Then the triangles $B\ A\ X$, $B\ A\ C$, are equal and similar by construction; also the triangles $D\ B\ C$, $B\ A\ C$, are similar; for $B\ E$ being a tangent to the circle, and $B\ X$, $B\ C$, drawn cutting the circle from the point of contact, the angles $X\ B\ F$, $C\ B\ E$ will equal the angles in the alternate segments of the circle [Euclid, B. iii. Prop. 32]; that is, $D\ B\ E$ and $C\ B\ E$ equal respectively $\frac{1}{2}\ X\ A\ B$, and $\frac{1}{2}\ B\ A\ C$, the angles at the centre.

Therefore in the similar triangles $B\ A\ C$, $D\ B\ C$

$$A\,B : B\,C :: B\,C : D\,C;$$

that is, radius : chord :: chord : offset,

$$\text{or, offset} = \frac{(\text{chord})^2}{\text{radius}}$$

Hence if the common four-pole chain be used to set out a curve, the length of the offset at the extremity of every one chain chord produced will be known, and the point in the periphery marked, from the preceding simple construction.

Suppose the radius of the curve is 100 chains, and the chord one chain;

then reducing all to inches (the statute four-pole chain containing 792) we have, as above—

$$100 \times 792 : 792 :: 792 : \text{offset} (= 7 \cdot 92).$$

If any other standard of measure than the four-pole chain be used the radius and chord must be expressed accordingly. Hence whatever chain or standard of measure is used we have the following rule :—

" Divide the number of inches in that chain by the number of such chains in the radius of the curve, and the quotient will be the offset required in inches."

Practice.

Let it be required to set out a curve of 100 chains radius.

Stake out any tangent line, as $F\ B$; then the distance of the point C from this line produced to E (one chain), for a one-chain chord of the curve, will be $\frac{1}{2}\ D\ C$, or $3 \cdot 46$ inches ; now one end of the chain being held at B, the position of the other end, C, will be ascertained by measuring $3 \cdot 46$ inches by means of an offset-staff, from the point E. That is, first measure one chain's length from B to E, and mark the point E, by a pole, or otherwise, and having one end of the chain held at B, move the other end from E, in the required direction, viz., towards C; the distance $E\ C$ being at the same time measured by an offset-staff, duly divided for the purpose.

As the angle $B\ E\ C$ is a right angle, an inconsiderable error is incurred by setting out an isosceles, instead of a right-angled triangle; but this would not be remedied in practice by setting out a right angle, because $B\ E$ is not truly a full chain in length.

The first point being determined, measure one chain on the chord $B\ C$ produced; that is, determine the point G, and if the end C is held fast, whilst the end G is moved to H, through the length of the full offset due to the required curve, measured with the staff as before, the point H is determined; and if $C\ H$ be produced to I, the point K may be determined in the same manner; and so on, by this simple use of the chain and offset-staff.

The offsets for curves of radii varying from 5 to 320 chains are given in a table at the end of this paper (p. 303).

Proposition II.

" To pass from a straight line into a curve of given radius."

This proposition is included in the preceding, supposing $F B$ to be the line from which it is required to pass into the curve $B C H$; the intermediate offset to the point C, and the successive points $H K$, &c. may be determined as already shown.

Proposition III.

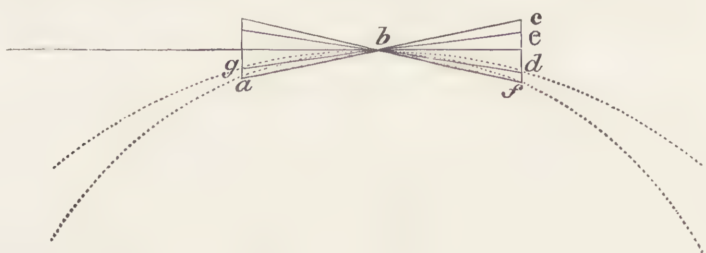
" To pass from a curve into a straight line."

Let $K C B$, Fig. 1, be the curve from which it is required to pass into the straight line $B F$. Produce $C B$ to L, that is, measure one chain forward; and as the distance $L M$ equals $C E$, let that distance, viz., half the offset of the given curve, be measured in the required direction, as before; when the line $B M$, being tangential to the curve, and in the desired direction, may be produced at pleasure.

Proposition IV.

" To pass from a curve of given radius to one of greater or less radius."

Fig. 2.



Case 1.

From a curve of given to one of less radius, as from the curve $g\ b\ d$ to the tangential curve $a\ b f$, of less radius.

Proceeding as before, the offset will be " the greater offset minus half the difference of the offsets." Thus, in Fig. 2, if the chord $g\ b$ is produced to e, the offset required will be $e f$; but $c f$ equals the greater offset, $e d$ the less, and $c e$ is half their difference.

Case 2.

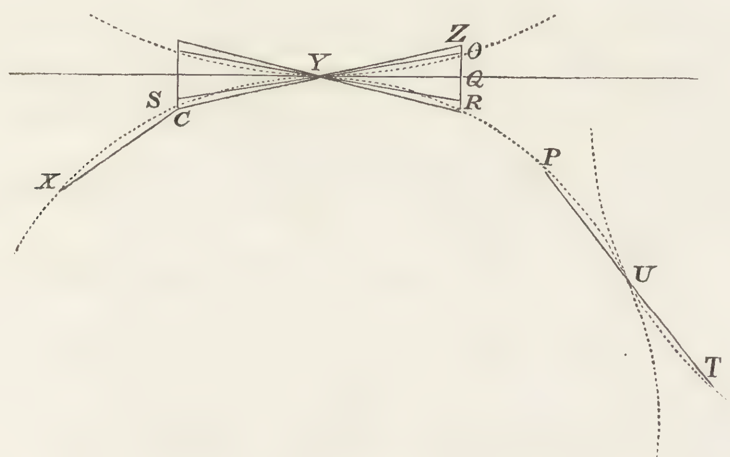
From a curve of given radius to one of greater radius, as from the curve $a\,b\,f$ (Fig. 2) to the tangential curve $g\,b\,d$, of greater radius.

The offset at the point of change will be "the less offset plus half the difference of the offsets." Thus, in Fig. 2, if the chord $a\,b$ is produced to c, the required offset will be $c\,d$, which equals $d\,e + e\,c$; but $d\,e$ equals the less offset, and $e\,c$ half the difference of the offsets.

Proposition V.

"To pass from a curve of given radius and flexure into one of contrary flexure."

Fig. 3.



Case 1.

From a curve of given radius to one of greater.

In passing out of the curve $X\,Y$ into the tangential curve $Y\,O$, if the chord $C\,Y$ be produced to Z, so that $Y\,Z$ equals $C\,Y$, then the distance to be set off will be $Z\,O$; but as has been already shewn, $Z\,Q$ equals half the offset due to the curve $X\,Y$, and $O\,Q$ half that of the curve $Y\,O$; hence it is evident, that at the extremity of the first chain of the new curve it is necessary to set out "half the difference" (or perhaps more obviously, "the difference of the halves") "of the respective offsets due to the two curves."

When passing out of one curve into another of greater radius, as in the present case, this half difference must be set out "in the same direction as if proceeding with *the first curve*," as from Z to O.

Case 2.

From a curve of given radius to one of less radius.

When passing out of the curve $O\,Y$ (Fig. 3) into the curve $Y\,X$; if the chord $O\,Y$ be produced to S, so that $Y\,S$ equals $O\,Y$, the distance to be set off will be $S\,C$, which again is " half the difference of the offsets;" but in this case it is evident the half difference must be set out " on the same side as the succeeding offsets of the *new curve*."

Case 3.

From a curve of given radius into one of the same radius.

In this case, as there is no difference of offsets, so there is no distance to be set off, and " the two chords constitute one right line, as $P\,U\,T$ (Fig. 3). Of course this line must not be taken at either a greater or a less length than double the chord in use.

If the turn at Y or at U (Fig. 3.) be too short for the ground, a common tangent should be interposed between the curves.

Proposition VI.

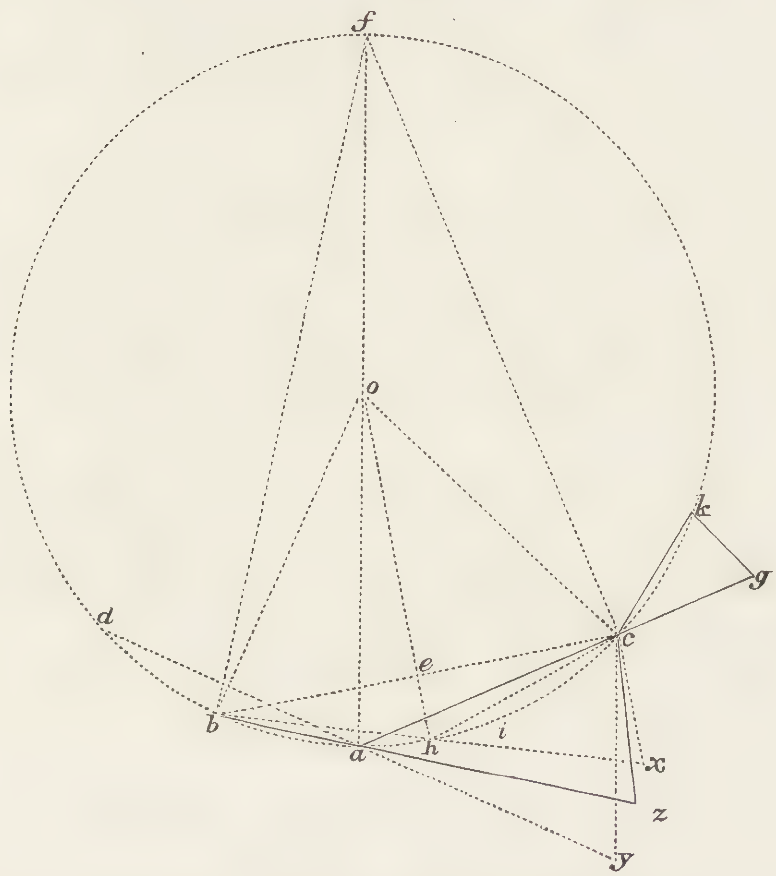
" To set out a curve when an obstruction occurs at a given point," as at i (Fig. 4).

In this case, as it is inconvenient at the point i to set out the usual chord, let any other chord be taken, as $a\,c$. Then $b\,a$ being the one-chain chord, let it be produced to z, and draw $a\,c = a\,z$; from the point a draw the diameter $a\,f$; draw $c\,f$ and $b\,f$, and the chord $b\,c$; bisect the arc $b\,c$ in h, and draw the radii $o\,b$, $o\,h$, and $o\,c$; draw $b\,h$ and $h\,c$; make $h\,x$ equal to $h\,c$; draw $a\,d$ equal to $a\,c$; connect the point c with x, z, and y, and those three lines, viz., $c\,x$, $c\,z$, and $c\,y$ will be in continued proportion; so that having found the first and third of them, the second being a mean proportional, will be known also.

Now $b\,f\,a$ and $a\,f\,c$ being right-angled triangles, $b\,f = \sqrt{a\,f^2 - a\,b^2}$, and $c\,f = \sqrt{a\,f^2 - a\,c^2}$; and $a\,b\,f\,c$ being a quadrilateral inscribed in a circle, the rectangle under the diagonals is equal to the sum of the rectangles under its opposite sides [Proposition CX., Cooley's Geometrical Propositions]; or $a\,f \times b\,c = a\,b \times c\,f + a\,c \times b\,f$; therefore $b\,c = \dfrac{a\,b \times c\,f + a\,c \times b\,f}{a\,f}$.

In the right-angled triangle $o\,e\,b$, $o\,b$ equals the radius, $b\,e$ equals half $b\,c$,

Fig. 4.



and $o\,e = \sqrt{o\,b^2 - b\,e^2}$; hence $o\,e$, and consequently $e\,h$, are known; and thus $c\,x$, which equals twice $e\,h$, is found.

The angles $b\,a\,c$ and $b\,h\,c$, being in the same arc of the circle, are equal; therefore their complements, $c\,a\,z$ and $c\,h\,x$, are equal; but those complements are respectively the vertical angles of isosceles triangles, therefore those triangles are similar, consequently $c\,x$ is to $c\,z$ as $c\,h$ is to $c\,a$; now $c\,x = \frac{c\,h^2}{o\,h}$, and $e\,y = \frac{c\,a^2}{o\,a}$ [Proposition I. of this paper]; that is, $c\,x : c\,y :: \frac{c\,h^2}{\text{rad.}} : \frac{c\,a^2}{\text{rad.}}$, consequently as $c\,h^2$ is to $c\,a^2$; but $c\,h^2 : c\,a^2 :: c\,x^2 : c\,z^2$; therefore $c\,x : c\,y :: c\,x^2 : c\,z^2$; then, multiplying the means and the extremes, $c\,x \times c\,z^2 = c\,y \times c\,x^2$, and dividing both sides by $c\,x$ we have $c\,z^2 = c\,y \times c\,x$, and therefore $c\,x : c\,z : c\,y$.

Practice.

Suppose $b\,a$ one four-pole chain, and $a\,z$ two chains in length; and the radius 100 chains; then

$$bf = \sqrt{158400^2 - 792^2} = 158398 \cdot 02, \text{ and}$$
$$cf = \sqrt{158400^2 - 1584^2} = 158392 \cdot 08, \text{ and}$$

$a\,f \times b\,c = a\,b \times cf + a\,c \times b\,f = 376{,}348{,}991 \cdot 04$; and

$b\,c = \dfrac{376{,}348{,}991 \cdot 04}{158400\ (= a\,f)} = 2{,}375 \cdot 94$; and $\dfrac{b\,c}{2} = b\,e = 1187 \cdot 97$.

Then $o\,e = \sqrt{o\,b^2 - b\,e^2} = \sqrt{6{,}272{,}640{,}000 - 1{,}411{,}272 \cdot 7209}$
$= \sqrt{6{,}271{,}228{,}727 \cdot 280} = 79{,}191 \cdot 089$; and

$e\,h = o\,h - o\,e = 79{,}200 - 79{,}191 \cdot 153 = 8 \cdot 911 = \dfrac{c\,x}{2}$; therefore

$c\,x = 17 \cdot 822$, and $c\,x^2 = 317 \cdot 624$; and $c\,y$ (by Proposition I.) $= 31 \cdot 68$.

But $c\,x \;:\; c\,y \;::\; c\,x^2 \;:\; c\,z^2$, therefore

$17 \cdot 822 \;:\; 31 \cdot 68 \;::\; 317 \cdot 624 \;:\; 564 \cdot 600$; and the square root of $564 \cdot 600$ is 24, which is the value of $c\,z$, the offset required.

It will be found, by a similar computation, that the offset for the extremity of the next following one-chain chord, as at g, should be 12 inches, viz., half the length just ascertained.

If the chord, instead of being produced two chains' length, be taken half a chain in length, then the offset will be $2 \cdot 97$ inches; and for the next following full chain double as much, or $5 \cdot 94$ inches.

It will be perceived that the offset "for double the chord, is rather more than three times the offset for the one-chain chord;" and "that for the half chord, rather more than one-third of the usual offset." Hence it appears that, practically speaking, a good approximation only can be arrived at, if the usual length of chord be departed from. For permanent work, therefore, all obstructions should be removed, previously to setting-out the curves of a line of railway.

CHARLES BOURNS.

SEGMENTAL CURVES.

Table of Offsets for each One-Chain Chord Produced.

Chains Radius.	Offsets.	Chains Radius.	Offsets.	Chains Radius.	Offsets.
	ft. in.		ft. in.		ft. in.
5 =	13 2·4	29 =	2 3·3	70 =	0 11·3
6 =	11 0·0	30 =	2 2·4	75 =	0 10·6
7 =	9 5·1	31 =	2 1·6	80 =	0 9·9
8 =	8 3·0	32 =	2 0·8	85 =	0 9·3
9 =	7 4·0	33 =	2 0·0	90 =	0 8·8
10 =	6 7·2	34 =	1 11·3	95 =	0 8·3
11 =	6 0·0	35 =	1 10·6	100 =	0 7·9
12 =	5 6·0	36 =	1 10·0	110 =	0 7·2
13 =	5 0·9	37 =	1 9·4	120 =	0 6·6
14 =	4 8·6	38 =	1 8·8	130 =	0 6·1
15 =	4 4·8	39 =	1 8·3	140 =	0 5·6
16 =	4 1·5	40 =	1 7·8	150 =	0 5·3
17 =	3 10·6	42 =	1 6·9	160 =	0 4·9
18 =	3 8·0	44 =	1 6·0	170 =	0 4·6
19 =	3 5·7	46 =	1 5·2	180 =	0 4·4
20 =	3 3·6	48 =	1 4·5	190 =	0 4·2
21 =	3 1·7	50 =	1 3·8	200 =	0 3·9
22 =	3 0·0	52 =	1 3·2	220 =	0 3·6
23 =	2 10·4	54 =	1 2·7	240 =	0 3·3
24 =	2 9·0	56 =	1 2·1	260 =	0 3·0
25 =	2 7·7	58 =	1 1·7	280 =	0 2·8
26 =	2 6·5	60 =	1 1·2	300 =	0 2·6
27 =	2 5·3	65 =	1 0·2	320 =	0 2·5
28 =	2 4·3				

XII.—*On the Locomotive Engines of the London and Birmingham Railway.*

By EDWARD BURY, M. Inst. C.E.

Read March 17th, 1840.

By the permission of the Board of Directors of the London and Birmingham Railway, I am enabled to furnish the Institution of Civil Engineers with the four Half-yearly Returns of the Locomotive department, on their line, between January 1839 and December 1840.

These returns are accompanied by a drawing of the Locomotive Engines to which they refer, with details of the principal parts; and as the quantity of coke consumed, as well as the cost of repairs, is much less than usual (which may, I conceive, be attributed to the system followed in the construction of the engines), I would make some observations upon those parts in which they more essentially differ from other locomotives. The first tabular statement of the performances of the engines is for the half-year ending 30th June 1839; it gives for each engine the number of miles it has passed over; the load conveyed, with the detailed cost of transport; the charges which cannot be fixed on any particular engine being proportioned among them. In the second half-year, ending the 31st December 1839, in addition to these particulars, is presented the distance performed by each engine from the time it first commenced working, together with the total repairs it has undergone during that period. It also shews the time it has been actually in motion during the periods named. The third and fourth returns are each preceded by a table, shewing the repairs the engines have undergone since the opening of the railway, as compared with the work they have performed. These accounts differ in form from the two preceding; they are much more detailed, and the engines of similar size and construction are classed together, so that the necessity of an account for each engine is avoided.

The London and Birmingham Railway is supplied in London with good coke made from Newcastle coal; but that obtained at Birmingham, from the Staffordshire coal, is of an inferior quality. For this reason the accounts

of the two kinds of coke are kept separate in the two first half-yearly returns.

During the whole of the year 1839 the average

	Quantity of Coke consumed per Mile run by the Engine.	Quantity of Coke consumed per Ton conveyed 1 Mile.	Cost of Repairs per Mile run by the Engine.	Cost of Repairs per Ton conveyed 1 Mile by the Engine.
For Passenger Engine	38·78 lbs.	0·86 lbs.	2·51 pence.	0·55 pence.
For Merchandize Engine	42·58 lbs.	0·56 lbs.	2·1 pence.	0·28 pence.

When compared with similar results obtained on other railroads, these returns exhibit a great economy in both items, which I attribute chiefly to the shape of the fire-box, to the inside framing, and to the use of four wheels instead of six.

The first engine which I made upon this construction was the "Liverpool;" it was commenced in October 1829, and set to work on the Liverpool and Manchester Railway in July 1830; since that period many improvements in the details have been introduced, but the general plan of construction has been steadily adhered to.

The Boiler. The most essential requisites in a locomotive boiler are, a great extent of heating surface in a small compass, and the arrangement of that surface so as to cause and promote a rapid circulation of the water. These principles have been kept in view in the disposition of the tubes and the shape of the fire-box.

Circulation of Water. The central tubes and the centre of the fire-box are nearest to the surface of the water, which is consequently hottest and lightest above those parts, and towards them the particles of water or globules of steam will rush; the outer tubes and sides of the fire-box being lower, and consequently cooler, establish a return current of the colder particles of water from the centre towards the sides and bottom of the boiler.

Fire-Tubes. This arrangement of the upper row of tubes has also the advantage of preventing any of them from being uncovered when the engine is travelling on sharp curves, where the centrifugal force throws the water to one side of the boiler.

Fire-Box. The fire-box is cylindrical, with its back flattened to receive the ends of the tubes: its top is a sphere merging into a cylinder or elongated cone, and all the curves are such as to enable the plates to resist the pressure of the steam without the assistance of ribs or stays, which so materially prevent the circulation of the water over square fire-boxes. The cylindrical-shaped fire-

box possesses a great superiority over a square one, inasmuch as the corners, in which the combustion is always languid, are avoided.

Lead-plug in the Fire-box. A lead-plug is placed at the culminant point of the dome-shaped top, and will therefore melt before any other part of the fire-box is left dry: in a fire-box with a flat top this would only occur when the whole was dry and probably injured.

The fire-box is made of wrought iron three-eighths of an inch thick, except the tube plate, which is half an inch thick. The joints are welded wherever they are in contact with the burning fuel, as a rivetted joint, from its presenting a double thickness of metal, will not long resist the intense heat to which it is exposed. If it were made of copper instead of iron the thickness of the metal must be greater, and the weight would be increased; and it will be seen, in a comparison of the engines having four and six wheels, that the lightness of the iron fire-box is a point of considerable importance.

Consumption of Water and Coke. It is practically found that the passenger engine consumes 75, and the merchandize engine 85 cubic feet of water per hour. This quantity is greater than that calculated from the steam's elasticity in the cylinders, and from the number of cylinders filled, and emptied, at the respective mean velocity of 30 miles per hour for the passenger, and 25 miles per hour for the merchandize engine. The difference is owing to the escape of steam through the safety-valves, and to the occasional slipping of the wheels on the rails when the load is heavy.

Hence the superficial heating surface to evaporate one cubic foot of water in an hour, will be in the boiler of the passenger engine 5·6 square feet, and in the boiler of the merchandize engine 6· square feet of heated surface. This is nearly double the effect produced in stationary boilers, and yet the result is obtained without any considerable sacrifice of fuel; for, including all the coke which is wasted throughout the year, when the fires are drawn or lighted, and that which is used in the workshops, &c. the merchandize engines only consume 12 lbs., and the passenger engines 15 lbs. of coke per cubic foot of water evaporated.

Taken together, these results are superior to any thing that has been obtained from long trials of any other description of locomotive boiler.

Steam Regulator. The other parts connected with the boiler which differ from the usual mode of construction are the steam cock, or regulator. This is shewn in detail in the Figures 1, 2, and 3, drawn to a scale of three inches to one foot.

Figure 1 gives a view of the plug or valve, which, when closed, fits into the seat *e* of Figure 3. It is provided with a handle (shewn broken at *f*) by which it can be turned round a quarter of a circle; a groove, or screw thread, of a four-inch pitch, is cut upon it at *a*, and when in its place the stud *b* is fitted into it. By this means, when the plug is made to revolve a quarter of a circle, the face *e* is drawn back one inch from its seat, leaving eleven square inches of passage for the steam, which flows in the direction of the curved arrow, without the passage being at all throttled or obstructed. When it is necessary to throttle the steam, the handle is fixed at any required angle between the points marked "open" and "shut," so that the steam-way is then accurately in proportion with that angle.

Figure 2 represents the mode of fixing the stud *b* in the groove *a*.

Fig. 1.

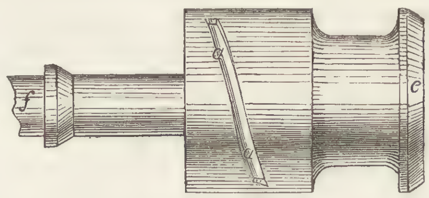


Fig. 2.

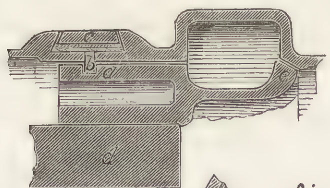
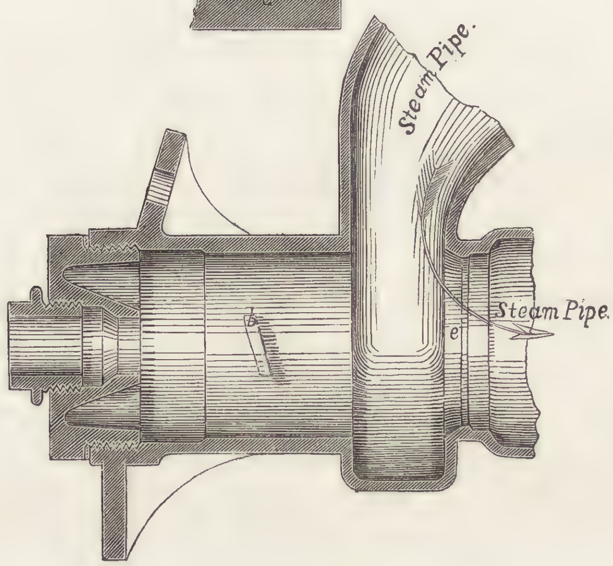


Fig. 3.



When the valve *e* is in its " seating," and the handle turned to " shut" in the quadrant, the stud *b* is dropped through a hole, which it fits accurately, as well as into the groove *a*, which is seen opposite the hole; at the back of the stud *b* are placed a strip of canvas and one of tin, and over them is driven a dove-tailed wedge *c*, which pressing on the elastic canvas renders the whole steam-tight.

This regulator enables the engine driver to govern the supply of steam with great precision, and it is not liable to get out of repair.

Force Pump. The section of the coupled engine (Plate I.) shews a longitudinal section through the pump, and Figures 4 and 5 (p. 310) are two transverse sections of it.

Figure 4, *h* is the working barrel, *i* is an intermediate pipe connecting it to the valve-box, and *g* is the delivery pipe fixed to the side of the boiler.

k is the inside frame, to which the pump is firmly secured; all the valves are the ordinary " clack-valves," *d* being an additional one to prevent any possibility of the return of hot water into the pump. The rod *l* is used to force the valve *a* into its seat, should the valve *b* not work perfectly tight: the small cock *f* is placed to ascertain if the flow of water into the pump is perfect.

Figure 5 is a section through the suction-valve, the play of the valve being limited by the piece *e*.

The pump is so constructed that any of the valves can be examined or replaced in a few minutes, and one of the pumps is more than sufficient for the supply of the boiler.

The Framing. The detailed drawing of the frame of the 13-inch coupled engine (Plate II.) shews the manner in which it connects all the parts of the engine and boiler together. (*See* the description of Plate II., p. 317.)

Next to a good boiler, which governs the economy of fuel, the most important point in the construction of a locomotive (inasmuch as it most materially influences the cost of repair) is to connect all the parts firmly together by a strong and well-arranged framing, so that they shall retain their relative positions when the engine is in motion, and that it shall receive and bear the strain and the concussions to which every part is subject. The inside framing possesses a great superiority, in this respect, over the outside framing, as it

Fig. 4.

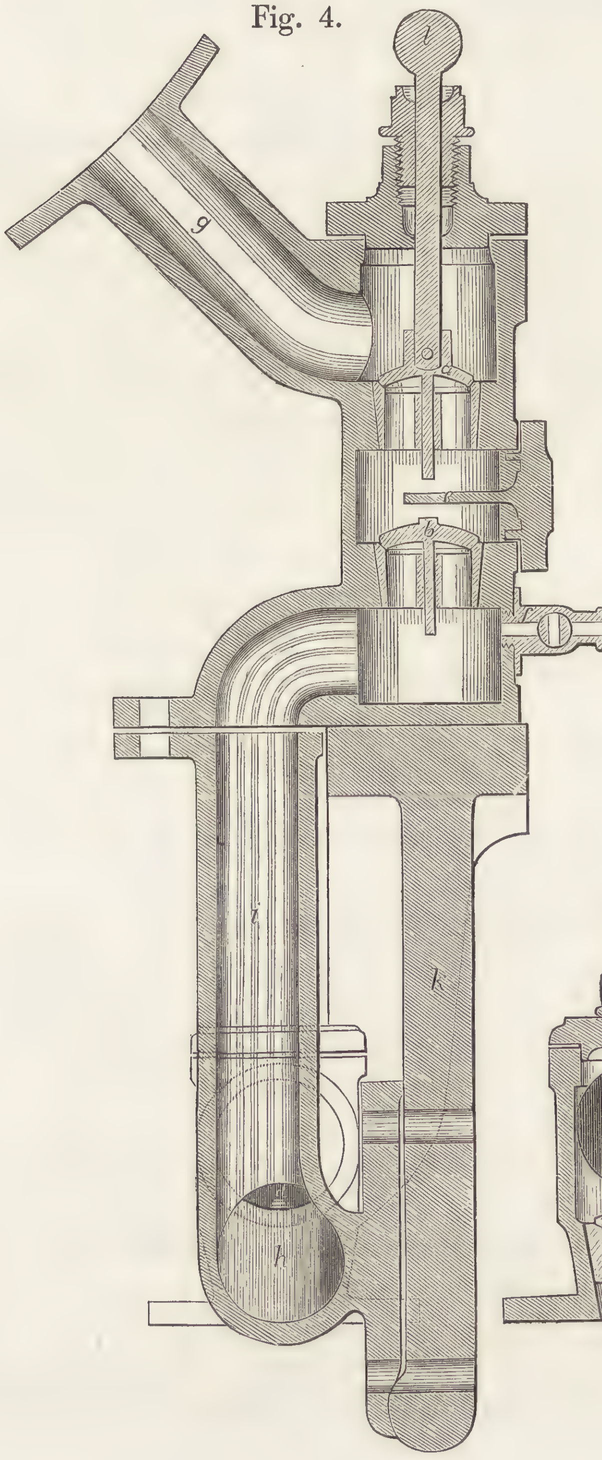
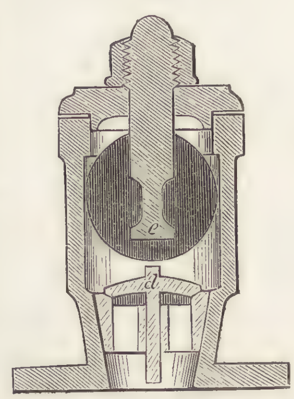


Fig. 5.



forms a stronger and more direct connexion between the cylinder, the cranked axle, and all the moving parts; and it bears all the strain of the engine without throwing any portion of it on the boiler, as is the case with the outside framing.

Comparison of inside with outside Framing. These advantages are best described by comparing it with the ordinary outside framing when submitted to the principal strains which it has to resist.

The most important is that caused by the whole power of the engine acting as a direct strain upon the crank as it passes over either centre.

With the inside framing the centre line of the connecting rod is only ten inches distant from the centre line of the frame, and the total distance between the bearings is $43\frac{1}{2}$ inches; but where the framing is outside the wheels, these dimensions are necessarily 20 inches and 72 inches respectively, and the effect of the strain on the crank in this case would be to its effect with the inside framing as 14 is to 8.

For this reason, when the principal frame is placed outside the wheels, it becomes necessary to have an additional inside framing, to prevent the fracture of the axle; these additional inside frames not only cause an increase of friction on the bearings of the cranked axle, but also throw a considerable strain on the boiler, which then becomes the medium of connexion between the inside and outside frames, the inside frames being fixed at one end to the bottom of the smoke-box, and at the other end to the fire-box; while the principal frame is attached by long brackets to the body of the boiler.

The fact that the use of four additional inside frames occasions six bearings on the axle (that axle being only six feet long), renders the system of principal outside framings so objectionable, that that circumstance alone should suffice to cause their rejection; for it is well known to practical men, that it is impossible to key so many bearings perfectly true, and to maintain them so, when the engine is working; and even if this precision were attained, the aggregate friction on the four inside and the two outside bearings would be much greater than when it is all thrown upon two bearings; because in the first place all the friction due to the weight of the boiler is borne by the two outside bearings alone, and that which results from the pressure of the steam, through the medium of the connecting rod, is thrown upon the four inside bearings; the pressure on the outside bearings is vertical, and the mean pressure on the inside bearings is nearly horizontal. So that if, instead of acting

separately, these two amounts of pressure were thrown on the same bearings, the friction would only be due to the resultant of the pressures, and would consequently be much reduced.

Friction on two Bearings. The friction on the cranked axle, having only two bearings, as where a single inside frame is used, will be, under ordinary circumstances, due to the resultant of the vertical and horizontal pressures, or—

$$\frac{\sqrt{12646^2 + 3000^2}}{8} = \frac{13000 \text{ lbs.}}{8} = 1625 \text{ lbs.}$$

In addition to the friction resulting from these forces there is a considerable pressure on the bearings, arising from the tightness of the brasses; and it is evident that the friction arising from this cause will be three times greater with six than with two bearings.

Strain on the Axles. Another important feature is the strain to which locomotive engines are liable, from the pressing or striking of the flanges of the wheels against the rail when travelling on a curve. In engines with the bearings inside the wheels, the weight of the boiler has a tendency to bend the axle down in the centre; while the pressure of the flange against the rail acts upon it in a contrary direction, and thus one strain counteracts the effect of the other. If the bearing is outside the wheel, the weight of the boiler tends to bend the axle upwards, and a strain on the flange of the wheel acts in the same direction and in addition to it.

The position of the bearings inside the wheels is of great practical advantage in case of the fracture of the cranked axle, as the weight on the bearings presses the flange of the wheel against the rail and assists the length of the journal in keeping it from being thrown off the rails. Instances have occurred on the London and Birmingham Railway, when an axle has broken, that not only have the wheels remained on the rails, but the driver has been enabled to proceed with the train to the nearest station.

Stiffness of the Framing. The stiffness of the single inside framing is not only a remedy against the excessive wear and tear which is consequent on a less perfect union between the parts of the engine, but its simplicity allows the whole machinery to be arranged in a more compact form and constructed with greater solidity. The valve gear is much simpler in its construction, and the engine driver, while standing on the foot-plate, can inspect the whole of the machine, and detect any derangement requiring his attention.

The Excentrics. The four excentrics are placed side by side, and are firmly connected together by bolts and snugs, so that the angle at which each is fixed cannot vary. This angle is governed in some measure by the nature of the work the engine is destined to perform. On the London and Birmingham Railway the excentrics are generally so placed as to cut off the steam when the piston is within $2\frac{3}{4}$ inches from the end of the stroke.

On the relative Advantages of Four and Six Wheels.

Comparison of four and six-wheeled Engines. It is admitted that a locomotive engine should be as light as is consistent with great strength, simple in its construction, be composed of as few parts as possible, and that the greatest regard is to be had to the diminution of friction; such being the case, it is obvious that four wheels must be preferable to six, provided that they carry the engine equally well.

The use of six wheels originated in the necessity of supporting the large and heavy fire-box of the engine, which was not sufficiently balanced by the smoke-box end; no such necessity exists in the locomotives of the London and Birmingham Railway, as the weight is nearly equally distributed on the front and hind wheels, and not only would two additional wheels be useless, but they would be prejudicial, especially when the engines are travelling upon curves.

A four-wheeled engine, travelling upon a curve, is driven, by the direct application of the moving power, towards the outside of the curve; but as the wheels are rather conical, the larger diameter of the cone will ride on the outside rail, while the smaller diameter of the opposite wheel will bear on the inside rail, and this difference (as the outside rail is longer than the inside one) will allow both the wheels to revolve without slipping or grinding.

With an engine upon six wheels, if the two leading wheels assumed this position, the others would necessarily be dragged after them; but a still more important case is, that the angle which the centre line of the locomotive forms with the tangent of the curve in which it is caused to move, is much greater with six wheels than with four; so that the flange of the wheel presses more against the rail with the former than with the latter engine.

The pressure against the outside rail arising from this cause, will be in direct proportion to the distance between the front and hind axle of either engine, so that it will be nearly as 10 : 6. This pressure and consequent

friction is still further increased by the action of the middle wheel, which tends to ride on the same curve as the front and hind wheels; but is prevented from doing so by being in a straight line between the two, and is thus forced to move laterally between the chord and the circumference of the curve. The friction arising from this lateral motion further presses the engine against the outside rail. Thus the four-wheeled locomotive has in proportion a greater weight on the front wheels, it presses less against the outside rail, and offers much less friction when travelling on curves—hence it has less tendency to be thrown off the rails; it is simple in its construction, less expensive in repairs on account of this simplicity, and its durability, as shewn in the accompanying Tables of the duty performed, and the small cost of it, fully justifies the preference given by the Directors of the London and Birmingham Railway to this description of engine.

EDWARD BURY.

Liverpool, 1840.

DESCRIPTION OF PLATE I.

The Plate represents the Merchandize Engine, with cylinders 13 inches diameter, and coupled wheels.

Fig. 1. Is a sectional elevation.

Fig. 2. A sectional plan, the line *x x* shewing the principal line of section followed in Fig. 1.

Fig. 3. A transverse section through the smoke-box.

To render the drawing more complete, several parts are shewn in each figure which do not come into view on the line of section.

The letters of reference correspond in all the figures.

A The fire-box.

B The fire-tubes; there are 96 tubes, 2 inches diameter each, and 9 feet long.

C The smoke-box.

D The regulator.

E The steam pipe, $3\frac{1}{2}$ inches diameter.

F The safety-valve and spring pressure gauge, $2\frac{1}{2}$ inches diameter.

G The locked-up safety-valve, $2\frac{1}{2}$ inches diameter.

H The damper.

I The buffer bar.

J The steam whistle.

L The steam cylinders, 13 inches diameter, 18 inches stroke.

M The force-pumps, plunger 2 inches diameter, 18 inches stroke.

N The cranked axle; the journals are 5 inches diameter and 7 inches long, the bearing of each crank is $5\frac{1}{2}$ inches diameter and $3\frac{1}{2}$ inches long.

O The connecting rods, oval-shaped, 2 inches by $2\frac{1}{2}$.

P The axle of the front wheels, $4\frac{1}{2}$ inches diameter.

Q The springs.—The springs for the cranked axle are composed of 16 plates, together $4\frac{1}{8}$ inches deep at the centre; those for the front axle are composed of 10 plates, together $3\frac{7}{8}$ inches deep at the centre.

a a The steam pistons, of gun metal. The packing consists of 2 rings of cast-iron segments forced outwards by brass wedges and steel springs. The piston-rods are 2 inches diameter.

b The inlet passages for the steam, $1\frac{1}{4} \times 6\frac{1}{2}$ inches.

c The outlet passage for the steam $1\frac{7}{8} \times 6\frac{1}{2}$ inches.

d The slide-valves.

d' The slide-valve rods, 1 inch diameter.

e The pendulum rods, for carrying the ends of the excentrics.

f The shaft, to which the excentric levers are fixed.

g The shaft connecting the motion of the lever *h*, and the rod *i*, to the shaft.
h The guides for the piston-rods.
i Steadying pieces for the guides.
j Shaft carrying the steadying pieces.
k l The rods for moving the slide-valves.
k′ l′ The levers of the hand-gear.
m The shaft carrying the valve trappings.
n The lever for working the valves.
n′ The lever worked by the excentrics.
p The excentrics for the retrograde motion.
q The excentrics for the advancing motion.
r The pipes (2 inches diameter) connecting the force-pumps with the tenders.
s The cock for letting the water out of the boiler.
t The rods ($1\frac{5}{8}$ inch diameter) for coupling together the front wheels and the driving wheels.
u A lead plug at the top of the fire-box.

DESCRIPTION OF PLATE II.

This plate shews the details of the framing of the Merchandize Engine. The letters correspond in all the figures.

a a Two straps firmly rivetted on each side to the frame, passing beneath and half round the cylinders, which are connected to them by being accurately fitted into snugs cast on the cylinders and rivetted to them.

b The crank axle.

c The axle of the front wheels.

d The springs.

e The transverse shaft for the steadying pieces of the guides.

f The bolt-holes for fixing the force-pumps on the frame.

g The buffer bar.

h The bolts for fixing the buffer bar to the frame.

i The bolt holes for the suspension rods of the springs.

k The cotter joints, connecting the lower with the upper part of the frame.

l & *m* Holes for receiving the draw-pin for connecting the tender with the engine.

n The holes for fixing the plate to the frame.

p The bracket connecting the frame with the fire-box.

q ,, ,, ,, body of the boiler.

r The strap connecting the lower part of the frame with the bottom of the fire-box, into which it is dovetailed and bolted.

LONDON AND BIRMINGHAM RAILWAY LOCOMOTIVE EXPENDITURE,
From 1st January to 30th June 1839.

PASSENGER ENGINES.

Number of Engine.	Miles Run.	Tons conveyed One Mile, exclusive of the Weight of the Engine and Tender.	COKE.						OIL.				Hose Pipes.		
			London (Good).	Birmingham (Inferior).	Total.	Cost.			Quarts.	Cost.					
			Cwts.	Cwts.	Cwts.	£.	s.	d.		£.	s.	d.	£.	s.	d.
1	7874	406,910	2150	144	2294	224	10	0	201	8	7	6	1	13	9
2	7294	330,568	2252	216	2468	238	14	0	162	6	15	0	0	10	6
3	7986	379,614	2448	241	2689	258	17	3	228½	9	10	5	2	0	0
4	7769	449,124	2664	114	2778	273	10	6	208½	8	13	9		..	
5	8987	333,782	1838	820	2658	235	13	1	217½	9	1	3	0	10	6
6	8661	365,550	2114	724	2838	257	4	6	246	10	5	0	2	9	6
7	14822	650,246	3699	798	4497	420	7	0	400½	16	13	9		..	
8	11548	452,254	2293	1040	3333	294	6	0	291	12	2	6		..	
9	10113	451,220	2572	698	3270	300	16	6	245½	10	4	7		..	
10	5656	276,108	1821	199	2020	194	10	9	157½	6	11	3	1	4	3
11	4672	201,036	1529	415	1944	179	3	0	165½	6	17	11		..	
12	5546	231,192	1616	785	2401	210	13	3	209	8	14	2	0	10	6
13	9044	358,190	2172	1038	3210	282	14	2	249½	10	7	11	0	5	3
14	4804	214,010	1308	244	1552	147	11	9	128	5	6	8		..	
15	8468	418,994	2479	153	2632	257	9	3	182½	7	12	1	0	9	6
16	5053	240,012	1657	212	1869	178	19	0	154½	6	8	9		..	
17	6822	287,552	1888	253	2141	204	12	3	148½	6	3	9		..	
18	5226	215,040	1497	327	1824	170	2	9	121	5	0	10	1	1	9
19	6185	210,110	1459	704	2163	190	0	8	166½	6	18	9		..	
20	8297	333,878	2312	283	2595	248	17	9	182½	7	12	1	0	5	3
21	4689	222,728	1564	175	1739	167	6	9	135½	5	12	11		..	
22	4666	192,272	1317	357	1674	154	0	3	138½	5	15	5	0	9	6
23	4920	226,882	1593	149	1742	168	12	3	149½	6	4	7	0	10	6
24	7688	378,062	2313	122	2435	238	18	6	183½	7	12	11	0	9	6
25	4375	224,788	1561	162	1723	166	4	6	114½	4	15	5		..	
26	2275	89,338	811	308	1119	100	9	0	79½	3	6	3	1	13	0
27	7330	270,182	1635	833	2468	215	11	3	178½	7	8	9	2	14	9
28	12160	463,098	2796	1341	4137	363	13	8	222	9	5	0	0	15	9
29	5986	240,506	1566	664	2230	198	2	0	181	7	10	10	0	10	6
30	7606	236,982	1993	262	2255	215	13	6	173	7	4	2	0	14	9
31	5132	236,588	1513	161	1674	161	7	3	138	5	15	0		..	
32	6287	296,788	2027	196	2223	214	19	0	178	7	8	4	0	9	6
33	5026	215,680	1220	604	1824	159	15	0	128	5	6	8	0	16	6
34	6641	254,542	1515	819	2334	202	13	9	220½	9	3	9		..	
35	4682	234,922	1156	575	1731	151	10	9	132	5	10	0	0	16	6
36	8822	376,896	2029	876	2905	257	13	0	258	10	15	0	6	10	3
	253,112	10,965,644	68,377	17,012	85,389	7905	3	10	6675½	278	2	11	27	11	9

London and Birmingham Railway Locomotive Expenditure, from 1st January to 30th June 1839, inclusive—(*continued*).

PASSENGER ENGINES.

Number of Engine.	Fire Tools.	Enginemen's and Firemen's Wages.	Repairs. Engine.	Repairs. Tender.	Files.	Summary.	Proportion of General Charges.
	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
1	0 4 8	45 4 8	74 4 5·50	14 0 5·8	0 11 3	368 16 8·58	114 4 6·47
2	..	49 3 4	29 7 0·29	7 7 0·28	0 4 5	332 1 3·57	103 5 9·43
3	0 11 1	45 11 9	38 5 3·67	5 3 8·71	0 12 9½	360 12 3·88	112 3 4·86
4	0 9 4	49 1 3	24 10 6·28	18 11 2·25	0 17 8	375 14 2·53	116 17 3·69
5	..	58 10 0	34 16 6·48	10 7 2·31	1 6 8½	350 5 3·29	108 19 0·05
6	..	59 2 6	66 0 4·36	2 6 7·32	0 15 0½	398 3 6·18	123 17 0·77
7	0 4 0	77 0 5	103 7 6·12	8 7 10·62	1 0 7	627 1 1·74	195 0 11·32
8	..	69 6 8	29 15 8·24	17 17 4·75	1 13 10	425 2 0·99	132 4 7·04
9	0 4 0	66 11 4	34 5 8·57	11 4 10·25	0 11 5	423 18 4·82	131 17 2·65
10	..	39 3 5½	80 16 7·20	8 3 5·50	2 9 9	332 19 6·20	103 11 5·44
11	0 4 8	63 14 0	51 3 9·11	9 16 10·28	1 12 2	312 12 4·39	97 4 9·70
12	..	56 15 4	38 16 2·35	14 1 5·79	1 13 7½	331 4 6·64	103 0 6·94
13	0 8 0	64 14 4	41 0 4·65	3 5 7·78	0 9 4	403 5 0·43	125 8 5·71
14	0 0 6½	30 18 1	15 4 7·65	1 7 10	0 12 8	201 2 2·15	62 11 1·26
15	..	51 0 11	41 5 11·41	0 1 3	1 5 6¾	359 4 6·16	111 14 9·05
16	0 4 8	40 8 1½	42 15 9·47	2 8 1·11	1 13 6	272 17 11·08	84 17 8·35
17	0 0 6	42 14 4	48 5 6·92	12 3 11·90	1 9 9½	315 10 2·32	98 2 9·55
18	0 5 8	44 4 6	75 2 11·10	10 1 4·97	1 0 7¼	307 0 5·32	95 9 11·94
19	..	42 9 1	92 6 7·48	3 11 9	1 4 1	336 10 11·48	104 13 8·10
20	0 5 6	47 5 6	55 17 9·87	4 17 2·38	0 19 11	366 1 0·25	113 17 2·58
21	0 4 8	31 10 6	25 1 6·81	11 4 5·75	0 17 5	241 18 3·56	75 4 11·52
22	0 4 8	44 5 2	32 5 1·70	1 10 2·87	0 14 2½	239 4 7·07	74 8 3·05
23	..	45 5 7	55 2 5·24	8 12 3·90	1 8 11	285 16 7·14	88 18 1·87
24	0 1 8	46 2 3	79 14 0·56	12 9 6·50	1 16 9	387 5 2·06	120 9 1·78
25	0 4 8	37 12 8	50 2 5·51	12 3 4·12	0 18 4	272 1 4·63	84 12 6·63
26	..	33 9 2	12 19 3·70	7 17 11·50	0 2 4	159 17 0·20	49 14 5·24
27	0 0 10	54 5 0	57 14 4·95	3 3 9·75	0 17 5½	341 16 3·20	106 6 5·18
28	0 4 0	73 9 7	81 0 11·29	9 3 8·43	1 15 11½	539 8 7·22	167 15 9·75
29	0 8 8	44 5 11	54 4 5·4	1 5 0·50	0 12 3	306 19 7·54	95 9 8·89
30	0 2 6½	45 0 1	52 8 11·21	3 5 9·15	1 8 11½	325 18 8·36	101 7 7·78
31	..	34 1 0	118 0 5·35	12 9 11·90	3 8 11	335 2 7·25	104 4 10·27
32	0 4 8	40 4 2	63 2 10·45	1 4 11·43	2 2 1½	329 15 7·38	102 11 6·92
33	0 4 0	44 9 6	70 15 11·67	11 14 2·50	0 15 3	293 17 1·17	91 8 0·99
34	..	66 13 4	42 14 6·3	5 9 4·9	2 5 0	328 19 8·12	102 6 7·46
35	0 4 8	41 7 6	70 2 3·32	2 16 3	3 0 10	275 8 9·32	85 13 6·16
36	0 8 8	61 15 0	83 15 3·51	2 4 9·75	3 8 4	426 10 4·26	132 13 4·57
	5 16 4	1786 16 0	1966 14 5·06	272 1 0·42	47 17 9	12,290 4 0·48	3822 17 6·96

London and Birmingham Railway Locomotive Expenditure, from 1st January to 30th June 1839, inclusive—(*continued*).

PASSENGER ENGINES.

Number of Engine.	Total Cost.			Average of Coke. Weight. Per Mile Run.	Average of Coke. Weight. Per Ton per Mile.	Average of Coke. Cost. Per Mile Run.	Average of Coke. Cost. Per Ton per Mile.	Average of Oil. Per Mile Run.	Average of Oil. Per Ton per Mile.	Cost of Repairs. Per Mile Run.	Cost of Repairs. Per Ton per Mile.	Total Cost. Per Mile Run.	Total Cost. Per Ton per Mile.
	£.	s.	d	lbs.	lbs.	d.	d.	Pints.	Pints.	d.	d.	d.	d.
1	483	11	3·05	32·63	·631	6·84	·132	·051	·98	2·69	·052	14·74	·285
2	435	7	1	37·89	·836	7·43	·163	·044	·98	1·20	·026	14·32	·316
3	472	15	8·74	37·71	·793	7·78	·138	·056	·120	1·30	·027	14·20	·298
4	492	11	6·22	41·33	·692	8·45	·146	·053	·92	1·33	·023	15·21	·263
5	459	4	3·34	33·12	·891	6·29	·169	·048	·130	1·20	·032	12·26	·330
6	522	0	6·95	36·69	·869	7·12	·168	·056	·134	1·89	·044	14·46	·343
7	822	2	1·06	34·	·774	6·80	·155	·054	·123	1·88	·041	13·30	·303
8	557	6	8·03	32·32	·825	6·11	·156	·050	·128	·99	·025	11·58	·295
9	555	15	7·47	36·21	·811	7·13	·160	·048	·108	1·08	·024	13·18	·295
10	436	10	11·64	40·	·819	8·24	·169	·056	·114	3·77	·077	18·52	·379
11	409	17	2·09	46·60	1·083	9·20	·213	·070	·164	3·13	·072	21·05	·489
12	434	5	1·58	48·30	1·163	9·11	·218	·075	·180	2·28	·054	18·79	·407
13	528	13	6·14	39·75	1·003	7·50	·189	·055	·139	1·17	·029	14·03	·354
14	263	13	3·41	36·18	·812	7·37	·165	·053	·119	·83	·018	13·17	·295
15	470	19	3·21	34·81	·703	7·29	·147	·043	·89	1·17	·023	13·34	·270
16	357	15	7·43	41·42	·872	8·49	·178	·061	·128	2·14	·045	16·99	·357
17	413	12	11·87	35·14	·832	7·19	·170	·043	·103	2·12	·050	14·55	·345
18	402	10	5·26	39·12	·950	7·81	·190	·046	·112	3·91	·095	18·48	·449
19	441	4	7·58	39·16	1·153	7·37	·217	·053	·159	3·72	·109	17·12	·504
20	479	18	2·83	35·	·870	7·19	·178	·044	·109	1·75	·043	13·87	·344
21	317	3	3·08	41·53	·874	8·56	·180	·057	·122	1·85	·039	16·23	·341
22	313	12	10·12	40·18	·923	7·92	·192	·059	·144	1·73	·042	16·13	·391
23	374	14	9·01	39·65	·859	8·22	·178	·060	·131	3·11	·067	18·28	·396
24	507	14	3·84	35·47	·718	7·45	·151	·047	·99	2·87	·058	15·84	·322
25	356	13	11·26	44·10	·859	9·11	·177	·052	·101	3·41	·066	19·56	·380
26	209	11	5·44	55·	1·401	10·59	·269	·069	·177	2·20	·056	22·10	·562
27	448	2	8·38	37·68	1·023	7·05	·191	·048	·132	1·99	·054	14·67	·398
28	707	4	4·97	38·10	1	7·17	·188	·036	·95	1·78	·046	13·95	·366
29	402	9	4·43	41·72	1·038	7·94	·197	·060	·150	2·22	·051	16·13	·401
30	427	6	4·14	33·20	1·065	6·80	·218	·045	·146	1·75	·056	13·48	·432
31	439	7	5·52	36·53	·792	7·54	·169	·053	·116	6·10	·132	20·54	·445
32	432	7	2·30	39·76	·832	8·22	·173	·056	·119	2·43	·052	16·50	·349
33	385	5	2·16	40·64	·942	7·62	·177	·050	·118	3·94	·091	18·39	·428
34	431	6	3·58	39·36	1·026	7·32	·191	·067	·173	1·74	·045	15·58	·406
35	361	2	3·48	41·40	·825	7·76	·154	·056	·112	3·73	·074	18·51	·368
36	559	3	8·83	36·88	·863	7·	·164	·058	·137	2·33	·054	15·21	·356
	16,113	1	7·44	37·78	·872	7·49	·173	·053	·121	2·12	·049	15·27	·352

London and Birmingham Railway Locomotive Expenditure, from 1st January to 30th June 1839, inclusive—(*continued*).

MERCHANDIZE ENGINES.

Number of Engine.	Miles Run.	Tons conveyed 1 Mile.	COKE. London (Good).	COKE. Birmingham (Inferior).	COKE. Total.	COKE. Cost.	OIL. Quarts.	OIL. Cost.	Hose Pipes
			Cwts.	Cwts.	Cwts.	£. s. d.		£. s. d.	£. s. d.
61	1900	173,778	720	91	811	77 13 9	56	2 6 8	0 9 6
62	5910	507,306	1658	514	2172	197 17 0	181½	7 11 3	0 16 6
63	3562	275,362	985	399	1384	123 8 9	133	5 10 10	0 10 6
64	2048	221,172	717	142	859	80 11 6	62½	2 12 1	..
65	5262	381,068	1432	591	2023	180 2 9	162	6 15 0	1 13 0
66	5658	503,694	1708	596	2304	209 1 0	159½	6 12 11	1 13 0
67	1641	211,756	595	61	656	63 6 3	49	2 0 10	0 19 0
68	2280	118,800	613	200	813	73 16 0	66½	2 15 5	..
69	2680	182,392	885	158	1043	98 7 6	81	3 7 6	..
70	7678	484,364	2045	648	2693	245 4 6	217	9 0 10	0 16 6
71	4380	194,400	967	408	1375	122 9 10	96	4 0 0	..
72	1980	93,210	443	188	631	56 7 7	44½	1 17 1	..
73	1260	57,600	301	125	426	37 18 3	35	1 9 2	..
79	2115	171,824	914	239	1153	106 6 9	61	2 10 10	0 16 6
80	3875	371,260	1521	152	1673	161 10 0	114	4 15 0	..
81	2957	312,516	1000	124	1124	107 15 0	82	3 8 4	1 1 0
82	3046	359,758	1142	135	1277	122 12 9	83½	3 9 7	0 10 6
83	2398	240,408	956	76	1032	100 7 0	69	2 17 6	0 19 0
84	4808	434,432	1718	187	1905	183 9 9	118	4 18 4	0 10 6
	65438	5,295,100	20,320	5034	25,354	2348 5 11	1871	77 19 2	10 15 6

London and Birmingham Railway Locomotive Expenditure,

MERCHANDIZE

Number of Engine.	Fire Tools.	Enginemen's and Firemen's Wages.	Repairs. Engine.	Repairs. Tender.	Files.	Summary.	Proportion of General Charges.
	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
61	..	11 9 2	34 6 4·07	17 14 1·86	0 15 3	144 14 9·93	45 0 5·29
62	..	29 18 7½	116 8 6·93	1 19 8·50	1 9 10	356 1 5·93	110 15 1·83
63	0 8 0	30 14 2	38 11 4·10	2 17 0	1 17 4	203 17 11·10	63 8 5·34
64	..	17 1 3	23 5 1·92	1 12 7·80	0 1 0	125 3 7·72	38 18 9·14
65	..	31 18 2	85 18 3·99	2 11 10	1 0 10	309 19 10·99	96 8 5·93
66	0 9 0½	28 14 2	33 19 7·45	2 10 6	1 17 3	284 17 5·95	88 12 2·58
67	..	9 11 5	15 10 0·85	1 7 4·50	0 5 6	93 0 5·35	28 18 8·36
68	..	11 7 6	9 1 4·25	1 1 9	0 2 6	98 4 6·25	30 11 0·80
69	..	14 11 3	5 10 5·08	0 16 8·50	0 1 5	122 14 9·58	38 3 6·82
70	0 9 4	37 18 4	26 14 8·40	1 16 4	0 19 10	323 0 4·40	100 9 6·09
71	..	23 5 10	16 16 9·12	1 12 10·50	0 14 10	169 0 1·62	52 11 4·75
72	..	10 5 10	36 14 0·15	0 15 2	..	105 19 8·15	32 19 3·95
73	0 3 2	2 3 4	1 9 0·87	..	0 3 5	43 6 4·87	13 9 5·96
79	0 4 8	14 14 4	21 8 0·63	0 4 8·50	0 2 4	146 8 2·13	45 10 9·77
80	..	25 5 4	29 16 1·71	1 6 10·75	0 1 5	222 14 9·46	69 5 8·03
81	0 5 6	17 10 9	13 1 9·93	..	0 4 4	143 6 8·93	44 11 8·46
82	0 5 6	16 16 5	20 18 8·12	..	1 1 0	165 14 5·12	51 10 11·52
83	..	11 15 5	8 18 4·46	0 2 6	0 3 10	125 3 7·46	38 18 9·05
84	0 1 8	27 2 5	20 8 6·85	0 16 6·32	0 13 10	238 1 7·17	74 1 1·23
	2 6 10½	372 3 8½	558 17 4·88	39 6 8·23	11 15 9	3421 11 0·11	4887 3 1·86
Fractional Differences							0 2 4·40
							4887 5 6·26
Aylesbury Railway, as per Statement, p. 324							..
Total Expenditure chargeable to the working of the Locomotive Engines							..

from 1st January to 30th June 1839, inclusive—(*continued*).

ENGINES.

Total Cost.			Average of Coke. Weight.		Average of Coke. Cost.		Average of Oil.		Cost of Repairs.		Total Cost.	
			Per Mile Run.	Per Ton per Mile.	Per Mile Run.	Per Ton per Mile.	Per Mile Run.	Per Ton per Mile.	Per Mile Run.	Per Ton per Mile.	Per Mile Run.	Per Ton per Mile.
£.	s.	d.	lbs.	lbs.	d.	d.	Pints.	Pints.	d.	d.	d.	d.
189	15	3·22	47·80	·522	9·81	·107	·058	·64	6·57	·071	23·97	·262
466	16	7·76	41·16	·479	8·03	·093	·061	·71	4·80	·056	18·95	·220
267	6	4·44	43·51	·563	8·31	·107	·074	·96	2·79	·036	18·	·233
164	2	4·86	46·97	·435	9·44	·087	·061	·56	2·91	·027	19·23	·178
406	8	4·92	43·05	·594	8·21	·113	·061	·85	4·07	·055	18·53	·255
373	9	8·53	45·60	·512	8·86	·099	·056	·63	1·54	·017	15·84	·177
121	19	1·71	44·77	·346	9·25	·071	·059	·46	2·46	·019	17·83	·138
128	15	7·05	39·98	·766	7·76	·149	·058	·112	1·06	·020	13·55	·260
160	18	4·40	43·58	·640	8·81	·129	·060	·89	·56	·008	14·41	·211
423	9	10·49	39·28	·622	7·66	·121	·056	·89	·89	·014	13·23	·209
221	11	6·37	35·16	·792	6·71	·151	·043	·99	1·01	·022	12·14	·273
138	19	0·10	35·69	·759	6·84	·145	·050	·95	4·54	·096	16·84	·357
56	15	10·83	37·86	·829	7·22	·158	·055	·121	·27	·006	10·81	·236
191	18	11·90	61·05	·752	12·06	·148	·059	·71	2·45	·032	21·78	·268
292	0	5·49	48·35	·504	10·	·104	·058	·61	1·92	·020	18·08	·188
187	18	5·39	41·32	·402	8·74	·082	·055	·52	1·06	·010	15·25	·144
217	5	4·64	46·95	·397	9·95	·081	·054	·46	1·01	·008	17·11	·145
164	2	4·51	48·20	·480	10·04	·100	·057	·57	·90	·008	16·42	·164
312	2	8·40	44·39	·491	9·15	·101	·049	·52	1·04	·011	15·57	·172
20,598	18	2·45	43·39	·536	8·61	·106	·057	·70	2·19	·027	16·44	·203
0	2	4·40										
20,599	0	6·85										
53	15	2·93										
20,652	15	9·78										

London and Birmingham Railway Locomotive Expenditure, from 1st January to 30th June 1839, inclusive—(*continued*).

ACCOUNT OF GENERAL CHARGES, included in the foregoing Statement.

				£.	s.	d.	£.	s.	d.
Pumping Engine at Camden				..			124	8	0·59
„ Tring				..			50	16	8·05
Accident Account				..			81	15	8·03
Repairs of Implements				..			42	17	2
Pumping Engine at Rugby				..			9	11	8·50
„ Coventry				..			3	2	5
„ Beechwood				..			0	8	3
Repairs of Wheels and Axles				..			167	8	0
„ Springs				..			80	10	0
General Charges, Coals and Firewood, London	£199	0	11						
Birmingham	211	11	4						
Wolverton	17	9	3						
				428	1	6			
Waste and Oil, London	69	2	11·25						
Birmingham	47	7	4						
Wolverton	25	6	4						
				141	16	7·25			
Cleaners' Wages, London	716	5	8						
Birmingham	859	15	6						
Wolverton	545	1	10						
				2121	3	0			
Painting, London	62	2	6·75						
Birmingham	73	15	3·25						
				135	17	10			
Stationery				57	15	1			
Clerks, Foremen, Watchmen, Office, and Sundry Expenses				1441	13	6·84			
							4326	7	7·09
						£	4887	5	6·26

ACCOUNT OF EXPENDITURE, AYLESBURY RAILWAY.

	£.	s.	d.
Coke	30	0	0
Oil	2	16	8
Hose Pipes	2	5	0
Engineman and Fireman's Wages	11	19	7
Repairs of Engine	4	6	3·93
Files, Oil Cans, Cleaning, &c.	2	7	8
	£53	15	2·93

	£.	s.	d.
Amount chargeable to the working Locomotive Engines	20,652	15	9·78
Stationary Engine for working Euston Square Incline, and sundry Expenses not chargeable to the working of the Locomotive Engines	2,526	7	3·22
Total Locomotive Expenditure	£23,179	3	1

1*st August*, 1839.

EDWARD BURY.

LONDON AND BIRMINGHAM RAILWAY LOCOMOTIVE EXPENDITURE,
From 1st July to 15th December 1839, inclusive.

PASSENGER ENGINES.

Number of Engine.	From the Opening of the Line to the 30th June 1839. Total Miles Run.	Total Cost of Repairs. £.	s.	d.	Miles Run from 1st July 1839 to 31st December 1839.	Tons conveyed 1 Mile.	Time of Performance. h.	m.	COKE. Weight. London (Good). Cwts.	Birmingham (Inferior). Cwts.	Total. Cwts.	Cost. £.	s.	d.
1	27527	260	4	2	7059 1904*	342,224	293	58	2151	227	2378	222	8	3
2	20222	149	16	5	5533 192*	219,686	233	29	1529	142	1671	161	15	6
3	14895	103	18	0	4977	215,948	211	10	1555	165	1720	165	16	3
4	14550	102	7	11	10563	515,813	428	16	3391	283	3674	357	10	9
5	17597	120	10	6	6960	292,483	272	22	1626	533	2159	202	4	1
6	16265	134	17	8	6185	279,150	256	22	1043	958	2001	179	6	7
7	25604	206	2	3	6328	316,454	264	47	1833	451	2284	212	4	9
8	19228	114	17	1	6591	323,959	323	47	1231	709	1940	174	7	10
9	17073	106	8	7	4500	249,252	194	18	1070	371	1441	133	0	2
10	24019	253	16	11	5138	247,754	202	9	1200	339	1539	145	13	0
11	18915	184	13	11	7579	331,892	325	57	2254	353	2607	247	9	3
12	14481	131	1	3	3711	204,435	170	24	766	1014	1780	160	5	0
13	18900	130	10	9	7044	324,180	297	8	1300	1159	2459	224	14	9
14	12206	81	7	10	7755	406,545	288	39	1825	240	2065	207	10	0
15	15198	100	4	11	8036 112*	338,839	334	2	2493	144	2637	258	6	0
16	15138	133	8	9	7804	339,180	338	7	2249	252	2501	240	13	0
17	21136	185	14	5	2109 5776*	103,891	89	10	721	59	780	75	15	9
18	18992	205	12	4	7606 256*	275,255	326	26	2459	260	2719	270	5	6
19	17386	193	18	6	6634	284,853	275	45	1887	809	2696	245	4	6
20	20780	169	19	6	5973	256,429	262	24	1846	155	2001	194	5	9
21	16357	138	7	10	7294 336*	341,283	341	59	2312	230	2542	245	11	6
22	13313	109	8	6	153	13,900	9	11	69	21	90	8	4	3
23	14913	237	5	6	3937 3152*	222,159	193	12	1314	162	1476	141	10	6
24	21662	214	9	0	7217	325,515	329	55	2389	286	2675	256	15	6
25	21136	208	18	11	5590 112*	266,566	261	14	2052	113	2165	212	17	9
26	5164	46	2	9	9745	342,005	387	50	1990	1080	3070	281	8	3
27	15575	133	1	0	..	..	..		..	..	..	..		
28	21531	172	3	7	4423	179,730	185	3	1122	656	1778	168	6	0
29	12172	110	13	7	5277	229,578	210	25	1462	641	2103	192	1	2
30	15964	128	17	3	5907	278,466	248	34	1893	336	2229	210	15	9
31	19494	255	3	9	8401	368,984	367	38	2615	226	2841	275	12	6
32	16105	150	5	11	6987	300,394	311	58	2239	156	2395	233	13	0
33	13691	158	6	6	6640	282,327	270	29	1450	1198	2648	238	14	10
34	16888	136	19	6	5375	236,545	218	28	1007	895	1902	169	14	9
35	9364	113	17	10	3360	268,190	183	42	790	547	1337	117	14	8
36	18568	171	5	7	5225	252,084	214	2	1210	857	2067	183	3	2
37	..	..			4182	197,637	157	41	764	637	1401	134	4	11
38	..	..			3240	140,398	113	21	581	344	925	91	16	7
39	..	..			1692	79,169	73	2	611	65	676	65	16	9
	622009	5554	15	8	222,730	10,193,152	9466	24	60,299	17,073	77,372	7306	18	6

* Aylesbury.

London and Birmingham Railway Locomotive Expenditure, from 1st July to 15th December 1839, inclusive—(*continued*).

PASSENGER ENGINES.

Number of Engine.	Oil.		Hose Pipes.	Fire Tools.	Enginemen's and Firemen's Wages.	Repairs.		Files.
	Quarts.	Cost.				Engine.	Tender.	
		£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d	£. s. d.	£. s. d.
1	167	6 19 2	0 19 0	..	39 16 7	167 4 11½	1 0 1½	0 9 9
2	144	6 0 0	1 18 0	..	33 3 2	111 16 3½	11 13 1	3 1 11
3	130½	5 8 9	3 4 0	0 4 0	29 11 4	52 16 2	8 16 2½	1 1 1
4	232½	9 13 9	1 18 0	0 4 0	64 4 8	57 10 2½	3 17 2	1 16 10
5	251	10 9 2	..	0 4 8	48 10 6	61 6 0½	2 10 7	1 2 3
6	211½	8 16 3	1 13 0	..	44 18 8½	37 12 4½	16 13 5	1 19 6
7	219½	9 2 11	0 16 6	0 4 0	39 8 5	143 9 3½	2 0 9½	3 4 0
8	202	8 8 4	0 16 6	0 4 0	50 17 8	68 4 2	11 11 2	4 11 9
9	135	5 12 6	1 13 0	..	23 4 2	35 18 2	3 3 6	1 7 1
10	147	6 2 6	3 8 6	0 4 0	27 9 2½	93 14 11½	6 15 0	1 3 3
11	174	7 5 0	1 6 0	0 4 0	54 4 4½	67 9 1	4 6 0	2 10 9
12	243½	10 2 11	2 9 6	..	50 19 8½	38 3 7½	3 8 3½	1 4 3
13	236½	9 17 1	..	..	49 5 8	66 8 6½	10 19 7½	0 19 0
14	147½	6 2 11	1 13 0	..	38 3 4	71 0 3	2 6 9	1 5 0
15	167	6 19 2	0 9 6	..	45 13 10	55 17 10½	3 1 10½	1 16 10
16	211	8 15 10	..	0 4 0	53 11 5½	41 5 8½	8 17 5½	1 1 4
17	58	2 8 4	0 19 0	..	15 16 9½	26 13 5½	6 2 2	0 15 9
18	219½	9 2 11	3 4 6	0 4 0	51 7 9½	44 18 7	4 13 0½	1 10 1
19	221	9 4 2	0 19 0	..	58 5 6½	61 15 9½	24 17 0½	0 5 5
20	164½	6 17 1	0 16 6	..	36 13 6½	47 0 10	7 17 7½	1 16 1
21	197½	8 4 7	0 19 0	..	41 9 4½	80 6 10	3 9 10	1 6 6
22	4	0 3 4	0 19 0	..	1 1 8	90 6 3½	1 3 2	0 17 11
23	108	4 10 0	2 7 6	..	36 6 8	74 12 8	4 16 3½	1 14 2
24	206½	8 12 1	3 4 0	0 4 0	50 13 0½	56 7 5	2 19 6½	1 14 7
25	179½	7 9 7	2 7 6	0 4 0	44 3 7	90 0 8½	8 19 8½	2 0 4
26	280½	11 13 9	1 6 0	0 1 10	58 5 11	32 1 4	0 17 2	0 9 6
27	..	..	..	..	..	62 13 5½	10 11 0½	3 0 2
28	181	7 10 10	..	..	51 10 7	79 5 6½	8 9 8½	1 4 4
29	190½	7 18 9	0 9 6	..	54 15 7	77 4 10	9 6 4	0 13 10
30	142½	5 18 9	1 18 0	0 4 0	43 13 1½	58 18 10	27 7 2½	1 8 11
31	234	9 15 0	7 7 3	0 8 0	52 2 0	48 1 1½	5 4 6	1 7 9
32	187	7 15 10	3 1 6	0 4 0	42 8 5½	87 2 0	4 4 3½	1 6 0
33	242	10 1 8	2 5 0	0 8 0	66 3 0½	80 9 0	7 11 6	2 11 4
34	215½	8 19 7	1 13 0	0 4 0	56 10 9½	82 4 10½	11 5 8½	3 4 4
35	138	5 15 0	..	0 4 0	36 8 0½	42 4 7½	1 17 7	1 14 7
36	242½	10 2 11	1 13 0	0 4 0	53 7 10½	69 18 0½	1 10 1½	2 16 6
37	177	7 7 6	0 19 0	0 4 0	19 8 10	16 0 11	0 10 9	0 6 8
38	106	4 8 4	..	..	11 3 4	15 0 5½	2 16 10½	0 4 5
39	49	2 0 10	..	0 4 0	8 15 10	3 5 0½	0 7 5	..
	6763½	281 17 1	58 12 9	4 10 6	1583 14 2½	2496 10 4½	257 19 8	61 3 9

London and Birmingham Railway Locomotive Expenditure, from 1st July to 15th December 1839, inclusive—(*continued*).

PASSENGER ENGINES.

Number of Engine.	Summary.	Proportion of General Charges.	Total Cost.	Average of Coke. Weight. Per Mile Run.	Average of Coke. Weight. Per Ton per Mile.	Average of Coke. Cost. Per Mile Run.	Average of Coke. Cost. Per Ton per Mile.	Cost of Repairs. Per Mile Run.	Cost of Repairs. Per Ton per Mile.	Total Cost. Per Mile Run.	Total Cost. Per Ton per Mile.
	£. s. d.	£. s. d.	£. s. d.	lbs.	lbs.	d.	d.	d.	d.	d.	d.
1	438 17 10	149 15 4	588 13 2	37·73	·778	7·56	·155	5·72	·118	18·45	·383
2	329 7 11½	112 8 11	441 16 10½	33·62	·851	7·	·176	5·35	·135	19·16	·482
3	266 17 9½	91 1 3	357 19 0½	38·70	·892	7·99	·178	2·97	·068	17·26	·397
4	496 15 4½	169 10 0	666 5 4½	38·95	·797	8·12	·166	1 39	·028	15·14	·310
5	326 7 3½	111 7 1	437 14 4½	34·74	·826	6·97	·160	2·20	·052	15·09	·359
6	290 19 10	99 5 10	390 5 8	36·23	·803	6·95	·172	2·10	·046	15·14	·335
7	410 10 8	140 1 8	550 12 4	40·42	·808	8·04	·160	5·51	·110	20·88	·417
8	319 1 5	108 17 4	427 18 9	31·44	·670	6·35	·129	2·89	·059	15·58	·317
9	203 18 7	69 11 7	273 10 2	36·18	·647	7·15	·123	2·10	·037	14·58	·263
10	284 10 5	97 1 8	381 12 1	33·54	·695	6·80	·141	4·69	·097	17·82	·369
11	384 14 5½	131 5 4	515 19 9½	38·52	·879	7·83	·178	2·27	·052	16·33	·373
12	266 13 3½	90 19 8	357 12 11½	53·72	·975	10·36	·180	2·69	·048	23·13	·419
13	362 4 8	123 11 11	485 16 7	39·09	·849	7·65	·166	2·63	·056	16·55	·359
14	328 1 3	111 18 9	440 0 0	29·81	·569	6·39	·124	2·27	·043	13·61	·259
15	372 5 1	127 0 3	499 5 4	36·75	·871	7·71	·179	1·76	·041	14·91	·353
16	354 8 9½	120 18 8	475 7 5½	35·89	·825	7·38	·170	1·54	·035	14·62	·307
17	128 11 3	43 17 4	172 8 7	41·42	·840	8·62	·175	3·73	·075	19·62	·398
18	385 6 5	131 9 6	516 15 11	40·03	1·106	8·52	·235	1·56	·043	16·30	·479
19	400 11 5½	136 13 6	537 4 11½	45·51	1·060	8·87	·206	3·13	·073	19·45	·452
20	295 7 5	100 15 11	396 3 4	37·52	·870	7·80	·181	2·20	·051	15·91	·370
21	381 7 7½	130 2 7	511 10 2½	39·16	·834	8·08	·107	2·75	·058	16·81	·359
22	102 15 7½	35 2 2	137 17 9½	65·88	·725	12·81	·141	143·10	1·579	216·29	2·380
23	265 17 9½	90 14 6	356 12 3½	41·99	·744	8·62	·152	4·84	·085	21·73	·389
24	380 10 2	129 16 8	510 6 10	41·51	·920	8·53	·189	1·97	·043	16·97	·376
25	368 3 2	125 12 4	493 15 6	43·37	·902	9·14	·191	4·25	·089	21·20	·444
26	386 3 9	131 15 4	517 19 1	35·28	1·005	6·93	·197	0·81	·023	12·75	·363
27	76 4 8	26 0 2	102 4 10								
28	316 7 0	107 18 9	424 5 9	45·	1·108	9·13	·224	4·76	·117	23·00	·566
29	342 10 0	116 17 3	459 7 3	44·63	1·026	8·73	·206	3·93	·091	20·89	·480
30	350 4 7	119 10 0	469 14 7	42·26	·896	8·56	·181	3·50	·074	19·08	·404
31	399 18 1½	136 9 0	536 7 1½	37·87	·862	7·87	·179	1·52	·034	15·32	·349
32	379 15 1	129 11 5	509 6 6	38·39	·892	8·02	·186	3·13	·072	17·49	·406
33	408 4 4½	139 5 9	547 10 1½	44·66	1·050	8·64	·202	3·18	·075	19·79	·465
34	333 17 0½	113 18 4	447 15 4½	39·63	·900	7·59	·172	4·17	·095	19·99	·454
35	205 18 6	70 5 3	276 3 9	44·56	·558	8·40	·105	3·15	·039	19·72	·247
36	322 15 7½	110 2 8	432 18 3½	44·30	·918	8·41	·174	3·28	·068	19·88	·412
37	179 2 7	61 2 5	240 5 0	37·54	·794	7·70	·162	0·95	·020	13·79	·291
38	125 10 0	42 16 5	168 6 5	31·97	·738	6·79	·156	1·32	·030	12·47	·287
39	80 9 10½	27 9 3	107 19 1½	44·74	·956	9·33	·198	0·51	·011	15·30	·327
	12,051 6 10	4112 1 9	16,163 8 7	38·90	0·850	7·87	·172	2·96	·064	17·41	·380

London and Birmingham Railway Locomotive Expenditure, from 1st July to 15th December 1839, inclusive—(*continued*).

MERCHANDIZE ENGINES.

Number of Engine.	From the Opening of the Line to the 30th of June 1839. Total Miles Run.	Total Cost of Repairs.	Miles Run from 1st July 1839 to 15th December 1839.	Tons conveyed 1 Mile.	Time of Performance.	COKE. Weight. London (Good).	Birmingham (Inferior).	Total.	Cost.
		£. s. d.			h. m.	Cwts.	Cwts.	Cwts.	£. s. d.
61	3184	63 5 2	7641	425,966	321 13	1896	745	2641	243 13 6
62	6630	124 14 3	6624	630,927	381 33	1691	998	2689	244 18 4
63	3802	43 10 4	4482	446,992	261 24	1083	723	1806	164 12 1
64	2048	24 17 10	7614	488,971	349 3	2582	264	2846	274 14 0
65	5262	88 10 2	7320	321,415	307 0	1512	1103	2615	227 3 10
66	5658	36 10 1	6084	614,419	353 44	1379	876	2255	200 7 9
67	1641	16 17 5	5208	554,244	347 16	1839	246	2085	199 5 6
68	2280	10 3 1	5172	245,291	214 1	1170	590	1760	159 6 8
69	2680	6 7 1	8238	495,130	365 42	2792	315	3107	298 17 9
70	7678	28 11 0	12042	592,525	488 19	2685	1225	3910	359 9 4
71	4380	18 9 7	10311	531,205	409 29	2039	1043	3082	286 16 4
72	1980	37 9 2	8184	379,337	323 5	1744	1146	2890	254 11 3
73	1260	1 9 1	5493	268,375	223 33	1241	786	2027	183 8 4
74	..	..	6840	683,443	395 52	1523	1235	2758	249 13 0
75	..	..	5586	285,036	233 48	1206	798	2004	178 8 6
76	..	..	4755	272,429	259 0	1597	211	1808	172 17 9
77	..	..	4980	504,095	277 25	1205	1178	2383	210 3 11
78	..	..	786	41,664	36 16	204	167	371	34 11 9
79	11607	55 19 11	6010	353,288	270 46	2039	166	2205	214 5 6
			112*						
80	11069	46 6 5	1617	81,188	69 8	457	158	615	55 11 6
			10300†						
81	7664	18 8 11	3774	403,200	253 7	1245	140	1385	133 5 0
			8400†						
82	4474	33 8 8	5966	692,567	388 46	2137	251	2388	229 7 9
83	3448	9 0 10	7362	720,523	438 50	2512	346	2858	273 13 2
84	4808	21 5 1	6879	509,146	315 57	2703	295	2998	288 14 9
85	..	..	9618	506,880	400 45	2424	972	3396	315 8 3
86	..	..	7041	359,843	300 35	1453	834	2287	210 8 6
87	..	..	3783	404,016	253 38	1472	177	1649	158 5 3
88	..	..	2043	229,784	139 13	851	62	913	88 19 6
			1500†						
89	..	..	1704	133,432	99 3	269	401	670	63 8 8
90	..	..	561	57,008	37 24	175	51	226	20 13 9
	91553	685 4 1	173,718	12232,339	8514 55	47,125	17,502	64,627	5995 1 2
			428,600 including Aylesbury and Ballasting.						
Total of Passengers and Goods Engines.	713562	6239 19 9	396,448	22,425,491	17,981 19	107,424	34,575	141,999	13,301 19 8
		Passenger Trains	326,681	5,176,845	13,596 59				
		Merchandize Trains	69,767	7,248,646	4,384 20				
			396,448	22,425,491	17,981 19				

* Aylesbury. † Ballasting.

London and Birmingham Railway Locomotive Expenditure, from 1st July to 15th December 1839, inclusive—(*continued*).

MERCHANDIZE ENGINES.

Number of Engine.	Oil. Quarts.	Oil. Cost.	Hose Pipes.	Fire Tools.	Enginemen's and Firemen's Wages.	Repairs. Engine.	Repairs. Tender.	Files.
		£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
61	250½	10 8 9	0 9 6	0 4 0	43 1 9	63 10 0½	4 1 3½	2 4 5
62	210	8 15 0	5 15 6	..	29 0 10	111 9 7	19 2 6½	1 15 11
63	134	5 11 8	0 16 6	0 9 0	24 10 9	43 3 5	18 0 10½	1 2 3
64	219	9 2 6	0 19 0	..	45 4 10	39 5 7½	10 0 8½	0 14 4
65	213	8 17 6	2 19 0	..	42 0 6	50 19 1½	1 7 1	1 6 5
66	163½	6 16 3	..	..	29 1 6	45 3 8	3 6 1	2 1 3
67	153½	6 7 11	..	..	29 2 11½	84 0 11½	4 5 9½	2 6 3
68	140½	5 17 1	1 13 0	..	27 6 10	29 2 1	0 10 6	0 13 3
69	224	9 6 8	..	..	43 19 4	37 13 7½	5 15 3	0 15 7
70	359	14 19 2	2 12 0	..	56 2 1½	52 0 1	4 5 1½	1 14 1
71	277	11 10 10	4 2 6	0 4 0	49 0 0	43 17 10	3 6 2½	1 17 7
72	251	10 9 2	2 19 0	..	39 11 1½	47 0 5½	2 6 4½	0 15 9
73	187	7 15 10	2 2 6	0 4 0	31 7 1	77 5 2	5 10 8	2 10 6
74	245½	10 4 7	0 16 6	..	37 15 0	28 13 7	3 7 3	1 14 9
75	222	9 5 0	0 16 6	0 4 0	24 19 2	30 11 8	0 11 2½	1 2 0
76	144	6 0 0	1 18 0	0 4 0	26 14 4	110 5 8	2 12 2½	2 7 5
77	193	8 0 10	1 13 0	..	25 2 1	36 5 0½	2 5 7	1 1 1
78	46	1 18 4	..	..	3 9 10	3 13 11	0 2 0	0 7 0
79	177½	7 7 11	0 19 0	..	33 17 6½	70 12 10½	0 1 1	1 9 2
80	61½	2 11 3	..	..	13 7 1	81 17 9	..	0 17 1
81	110	4 11 8	0 19 0	0 8 0	20 2 11	33 3 2	..	1 6 3
82	142½	5 18 9	..	..	30 10 4	58 12 0	0 16 0½	1 14 9
83	194½	8 2 1	2 2 6	..	37 4 5	38 16 4½	0 3 9	0 9 4
84	206½	8 12 1	2 5 0	..	39 8 10½	50 2 8½	18 14 11½	1 3 3
85	325½	13 11 3	0 16 6	0 4 0	45 15 2	16 9 6	0 0 6	1 0 2
86	182½	7 12 1	0 4 0	..	30 5 2	15 19 8	0 12 6	0 5 4
87	121½	5 1 3	0 9 6	..	19 0 0	19 10 11	0 2 1½	0 6 0
88	71½	2 19 7	0 19 0	0 5 0	13 10 9	20 12 11½	..	0 8 0
89	54	2 5 0	..	..	7 6 6	5 3 0½	0 3 6	0 2 6
90	31	1 5 10	..	..	2 14 2	1 7 0½	..	..
	5311	221 5 10	38 7 0	2 6 0	900 12 11½	1346 9 6½	111 11 2½	35 11 8
Total of Passengers and Goods Engines.	12,074½	503 2 11	96 19 9	6 16 6	2484 7 2	3842 19 11	369 10 10½	96 15 5

London and Birmingham Railway Locomotive Expenditure, from 1st July to 15th December 1839, inclusive—(*continued*).

MERCHANDIZE ENGINES.

Number of Engine.	Summary.	Proportion of General Charges.	Total Cost.	Average of Coke.				Cost of Repairs.		Total Cost.	
				Weight.		Cost.					
				Per Mile Run.	Per Ton per Mile.	Per Mile Run.	Per Ton per Mile.	Per Mile Run.	Per Ton per Mile.	Per Mile Run.	Per Ton per Mile.
	£. s. d.	£. s. d.	£. s. d.	lbs.	lbs.	d.	d.	d.	d.	d.	d.
61	367 13 3	125 9 0	493 2 3	38·71	·694	7·65	·137	2·12	·037	15·48	·277
62	420 17 8½	143 12 2	564 9 10½	45·46	·477	8·87	·093	4·73	·049	20·45	·214
63	258 6 6½	88 2 10	346 9 4½	45·17	·452	8·81	·088	3·32	·032	18·55	·186
64	380 1 0	129 13 6	509 14 6	41·86	·652	8·65	·134	1·46	·024	16·06	·249
65	334 13 5½	114 3 10	448 17 3½	40·	·911	7·44	·169	1·71	·039	14·71	·335
66	286 16 6	97 17 4	384 13 10	41·57	·411	7·90	·079	1·91	·019	15·17	·150
67	325 9 4½	111 1 0	436 10 4½	44·83	·421	9·18	·086	2·15	·038	20·11	·189
68	224 9 5	76 11 8	301 1 1	38·11	·803	7·39	·155	1·37	·029	13·97	·294
69	396 8 2½	135 5 1	531 13 3½	42·24	·703	8·70	·145	1 26	·021	15·49	·257
70	491 1 11	167 11 3	658 13 2	36·36	·739	7·16	145	1·12	·022	13·12	·266
71	400 15 3½	136 14 10	537 10 1½	33·47	·649	6·67	·129	1·09	·021	12·51	·395
72	357 13 1½	122 0 8	479 13 9½	39·55	·853	7·46	·161	1·44	·031	14·06	·306
73	310 4 1	105 16 10	416 0 11	41·33	·846	8·	·164	3·63	·074	18·16	·372
74	332 4 8	113 7 2	445 11 10	45·16	·463	8·76	·087	1·12	·011	15·63	·154
75	245 18 0½	83 18 0	329 16 0½	40·18	·787	7·66	·150	1·33	·026	13·98	·277
76	322 19 4½	110 3 11	433 3 3½	42·58	·743	8·72	152	5·69	·099	21·86	·382
77	284 11 6½	97 1 11	381 13 5½	53·59	·529	10·13	·100	1·85	·018	18·39	·179
78	44 2 10	15 1 2	59 4 0	52·86	·997	10·56	·199	1·15	·021	18·07	·241
79	328 13 1	112 2 9	440 15 10	41·09	·699	8·55	·145	2·82	·048	17·60	·299
80	154 4 8	52 12 6	206 17 2	42·59	·848	8·24	·164	12·15	·242	30·70	·611
81	193 16 0	66 2 6	259 18 6	41·10	·384	8·47	·079	2·03	·019	16·53	·154
82	326 19 7½	111 11 4	438 10 11½	44·83	·386	9·23	·079	2·38	·020	17·64	·152
83	360 11 7½	123 0 7	483 12 2½	43·48	·444	8·92	·091	1·27	·013	15·76	·162
84	409 1 7½	139 11 7	548 13 2½	48·86	·659	10·07	·136	2·40	·032	19·14	·259
85	393 5 4	134 3 8	527 9 0	39·54	·750	7·87	·149	0·41	·007	13·16	·249
86	265 7 3	90 10 10	355 17 1	36·37	·711	7·17	·140	0·56	·011	12·12	·237
87	202 15 0½	69 3 7	271 18 7½	48·82	·457	9·77	·094	1·24	·011	17·25	·161
88	127 14 9½	43 11 8	171 6 5½	50·05	·445	10·45	·093	2·42	·021	20·12	·178
89	78 9 2½	26 17 11	105 7 1½	44·03	·562	8·93	·114	0·74	·009	14·83	·189
90	26 0 9½	8 17 8	34 18 5½	45·11	·444	8·85	·087	0·57	·005	14·94	·147
	8651 4 4½	2951 18 9	11,603 3 1½	41·66	0·591	8·28	·117	2·01	·028	16·03	·227
Total of Passengers and Goods Engines.	20,702 12 2½	7064 0 6	27,766 12 8½	40·11	·709	8·05	·142	2·55	·045	16·80	·297
	504 19 7	172 2 0	677 1 7	Aylesbury Railway, as per Statement, p. 331.							
		7236 2 6									
		£	28,443 14 3½	Total Expenditure chargeable to the working of the Locomotive Engines							

London and Birmingham Railway Locomotive Expenditure, from 1st July to 15th December 1839, inclusive—(*continued*).

ACCOUNT OF GENERAL CHARGES included in the foregoing Statement.

	£.	s.	d.	£.	s.	d.	£.	s.	d.
Pumping Engines—Camden	88	13	0						
Tring	39	1	8						
Rugby	11	8	0						
Weedon	10	8	8						
Coventry	12	8	3						
Beechwood	7	4	6						
				..			169	4	1
Stationary Engine, Wolverton				..			20	3	10
Accident Account				..			556	17	9½
Implements and Repairs of ditto				..			595	12	7
Repairs of Wheels and Axles				..			93	1	0
„ Springs				..			40	1	0
Coals and Firewood—London				221	16	1½			
Birmingham				30	18	3			
Wolverton				226	8	3½			
							479	2	8
Stationery				..			114	16	1
Waste and Oil for Cleaners—London				95	19	0			
Birmingham				57	13	8			
Wolverton				85	5	5½			
							238	18	1½
Cleaners' Wages—London				836	6	2			
Birmingham				894	1	5½			
Wolverton				769	5	9½			
							2499	13	5
Painting—London				77	8	11½			
Birmingham				38	0	6½			
Wolverton				31	14	4			
							147	3	10
Clerks, Foremen, Watchmen, Office, and Sundry Expenses				..			2281	8	1
				£			7236	2	6

STATEMENT OF EXPENDITURE, AYLESBURY RAILWAY.

	£.	s.	d.
Coke, 3473 cwts.	347	6	0
Oil, 262 quarts	10	18	4
Hose Pipes	0	9	6
Engineman's and Fireman's Wages	108	14	9½
Repairs, Engine	7	8	0½
Repairs, Tender	0	4	0
Oil and Waste for Cleaners	2	6	0
Cleaner's Wages	23	16	11
One Signal Lamp, and fitting ditto	3	16	0
	£ 504	19	7

	Miles.
No. 1	1904
2	192
15	112
17	5776
18	256
21	336
23	3152
25	112
79	112
	11,952

	£.	s.	d.	£.	s.	d.
Expenditure, as per above Statement				28,443	14	3½
Stationary Engine for working Euston Incline, and Sundry Expenses not chargeable to working of Locomotive Engines				1,787	1	9
Total Expenditure to 15th December				30,230	16	0½
Amount of Pay Bills for Wages for the fortnight, from the 14th to 31st December 1839	£1009	1	9			
Sundries not classed	6	1	3			
				1,015	3	0
				£ 31,245	19	0½

January 31*st*, 1840.

EDWARD BURY.

LONDON AND BIRMINGHAM RAILWAY LOCOMOTIVE POWER ACCOUNT.

REPAIRS OF ENGINES AND TENDERS,
From the Commencement of their Running to the 14th June 1840.

	Total.	DIVIDED ACCORDING TO THOSE THAT HAVE RUN				
		Under 10,000 Miles.	Above 10,000 Miles.	Above 20,000 Miles.	Above 30,000 Miles.	Above 40,000 Miles.
Number of Locomotives	82	15	29	24	13	1
Total Number of Miles Run	1,635,396	89,266	444,421	629,833	429,944	41,932
Average Number of Miles Run per Engine	19,944	5,951	15,328	26,243	33,073	41,932
	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
Total Cost of Repairs .	17346 9 8	529 8 9	4467 3 7	6905 15 0	4952 11 0	491 11 4
Average Cost of Repairs per Engine .	211 10 10	35 5 11	154 0 10	287 14 9	380 19 4	491 11 4
	d.	d.	d.	d.	d.	d.
Ditto ditto per Mile .	2·545	1·423	2·412	2·631	2·765	2·813
	£. s. d.	s. d.	£. s. d.	£. s. d.	£. s. d.	s. d.
Ditto ditto per Journey of 111 Miles . .	1 3 6	13 2	1 2 4	1 4 4	1 5 7	1 6
	d.					
For the first 10,000 Miles, the Cost of Repairs, per Engine, and per Mile . .	2					
Ditto 20,000 ditto, ditto	2·5					
Ditto 30,000 ditto, ditto	2·667					
Ditto 40,000 ditto, ditto	2·750					
For the Second 10,000 ditto, ditto . .	3					
For the Third 10,000 ditto, ditto . .	3					
For the Fourth 10,000 ditto, ditto . .	3					

LOCOMOTIVE POWER ACCOUNT,

From 15th December 1839 to 14th June 1840.

	Total.	DIVIDED ACCORDING TO ENGINES HAVING		
		Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Wheels, 5 ft. 6 in. Diameter; One Pair Driving Wheels.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in. Wheels, 5 ft. 6 in. Diameter; One Pair Driving Wheels.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in. Wheels, 5 ft. Diameter; Coupled Wheels.
Number of Locomotives	82	42	10	30
Ditto Miles Run since Opening of Railway to June 14, 1840	1,635,396	1,063,210	92,101	480,085
Average Number of ditto by each Engine.	19,944	25,315	9,210	16,003
Number of Miles Run from December 14, 1839, to June 14, 1840	474,154	215,745	82,987	175,422
Ditto, with Passenger Trains	383,858	207,400	82,747	93,711
Ditto, with Merchandize Trains	90,296	8,345	240	81,711
Total Number of Journeys of 111 Miles	4,272	1,944	748	1,580
Ditto with Passenger Trains	3,459	1,869	746	844
Ditto with Merchandize Trains	813	75	2	2
Greatest Number of Miles Run by any one Engine	. .	9,778	15,228	9,960
Total Number of Passengers conveyed one Mile (distance 112 Miles)*	21,582,872			
Ditto apportioned among the several Engines, according to Gross Load	. .	10,430,636	5,275,291	587,695
Total Number of Passengers conveyed one Mile (distance 111 Miles)	21,390,167			
Ditto apportioned among the several Engines	. .	10,337,505	5,228,190	5,824,672
Average Number of Passengers per each Journey	. .	50	63	62
WEIGHT CONVEYED.	Tons.	Tons.	Tons.	Tons.
Estimated Gross Weight of each Passenger† with his Luggage	0·551			
Ditto Net Weight ditto ($2\frac{1}{4}$ cwt.)	0·1125			
Ditto ditto Horses (9 cwt.)	0·22222			
Ditto ditto Carriages	1·			
Ditto ditto Dogs (42 lbs.)	0·01873			
Ditto ditto Mail Bags, per diem (4 tons, 8 cwt. 2 qrs.)	4·425			
Ditto ditto Cattle ($5\frac{1}{2}$ cwt.)	0·275			
Ditto ditto Sheep ($\frac{3}{4}$ cwt.)	0·0375			
Ditto ditto Pigs (1 cwt.)	0·05			
Gross Load ‡ conveyed one Mile	24257775·	8021312·	3765571·	12470872·
Ditto by Passenger Trains	15347832·	7417347·	3751321·	4179164·
Ditto by Merchandize Trains	8909943·	603965·	14250·	8291728·
Net Load estimated from the above weights	7028463·	1779221·	772606·	4776636·
Ditto by Passenger Trains	3135503·	1515335·	766380·	3135503·
Ditto by Merchandize Trains	3892960·	263886·	6226·	3892960·
Average Gross Load per each Journey of the Engine (111 Miles) by Passenger Trains	39,983	35,763	45,335	44,596
Ditto by Merchandize Trains	98,675	72,374	59,375	101,476

* The distance, according to the mileage duty, is 112 miles, but a portion of that distance, at the London end, being performed by a fixed engine, the distance run by the engine is only 111 miles.

† This includes the portion of the weight of the train due to one passenger.

‡ Gross load includes the weight of the carriages (5 tons each), but not the weight of the engine and tender.

LOCOMOTIVE POWER ACCOUNT,

From 15th December 1839 to 14th June 1840—(*continued*).

	Total.	DIVIDED ACCORDING TO ENGINES HAVING		
		Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Wheels, 5 ft. 6 in. Diameter; One Pair Driving Wheels.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in; Wheels, 5 ft. 6 in. Diameter; One Pair Driving Wheels.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Wheels 5 ft. Diameter; Coupled Wheels.
RATE OF SPEED.	Hours. Minutes.	Hours. Minutes.	Hours. Minutes.	Hours. Minutes.
Total Time the Passenger Trains were in Motion	15382 21	8385 59	3119 39	3876 43
Average ditto ditto, per each Journey .	4 27	4 29	4 11	4 35½
	Miles per Hour.	Miles per Hour.	Miles per Hour.	Miles per Hour.
Average Speed of Passenger Trains . .	24·954	24·732	26·524	24·173
Ditto of Merchandize Trains	20	20	20	20
COKE CONSUMED.	Tons. cwts. qrs. lbs.	Tons. cwts. qrs. lbs.	Tons. cwts. qrs. lbs.	Tons. cwts. qrs. lbs.
Total Quantity	8405 8 0 0	3608 6 0 0	1298 2 0 0	3499 0 0 0
Quantity per Journey	1 19 1 11	1 17 0 14	1 14 2 25	2 4 1 3
Ditto per Hour	0 8 1 22	0 8 0 22	0 8 1 4	0 8 3 3
Ditto per Mile	0 0 1 11·709	0 0 1 9·464	0 0 1 7·039	0 0 1 16·679
Ditto per Ton of Gross Load per Mile .	0 0 0 0·776	0 0 0 1·007	0 0 0 0·772	0 0 0 0·630
Ditto ditto per Journey	0 0 3 2	0 1 0 0	0 0 3 1	0 0 2 14
OIL CONSUMED.	Quarts.	Quarts.	Quarts.	Quarts.
Total Quantity	15675·5	6905·	2540·	6230·5
Quantity per Journey	3·670	3·552	3·397	3·936
Ditto per Mile	0·0331	0·032	0·0306	0·0354
COST OF COKE.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
Total Cost, at an Average of 40*s.* per ton.	16810 2 3	7216 2 9	2596 4 0	6997 15 6
Cost per Engine per Journey (111 Miles)	3 18 8	3 14 3	3 9 5	4 8 7
Ditto per Hour	0 16 11	0 16 5	0 16 7	0 17 7
Ditto per Mile	0 0 8·509	0 0 8·027	0 0 7·508	0 0 9·574
Ditto per Ton of Gross Load per Mile. .	0 0 0·166	0 0 0·216	0 0 0·165	0 0 0·135
Ditto ditto per Journey	0 1 6·459	0 2 0	0 1 6·37	0 1 2·94
COST OF OIL.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
Total Cost	653 2 11	287 13 9	105 17 1	259 12 1
Cost per Engine per Journey (111 Miles)	0 3 0	0 2 11·520	0 2 9·977	0 3 3·427
Ditto per Mile	0 0 0·330	0 0 0·320	0 0 0·306	0 0 0·355
COST OF REPAIRS.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
Total Cost per Engine and Tenders, as below	6991 16 4	4835 19 9	501 6 4	1654 10 3
Ditto per Journey (111 Miles) . . .	1 12 8	2 9 9	0 13 5*	2 0 11
Ditto per Mile	0 0 3·539	0 0 5·380	0 0 1·450	0 0 2·264
Ditto per Ton of Gross Load per Mile .	0 0 0·069	0 0 0·145	0 0 0·032	0 0 0·032
Ditto ditto per Journey	0 0 7·678	0 1 4·060	0 0 3·546	0 0 3·534

* To account for this low figure it must be remarked that only 9114 miles had been run by the engines previous to December 14, 1839.

LOCOMOTIVE POWER ACCOUNT,

From 15th December 1839 to 14th June 1840—(*continued*).

COST OF LOCOMOTIVE POWER.	Total.			DIVIDED ACCORDING TO ENGINES HAVING								
				Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Wheels 5 ft. 6 in. Diameter; One Pair Driving Wheels.			Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Wheels, 5 ft. 6 in. Diameter; One Pair Driving Wheels.			Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Wheels, 5 ft. Diameter; Coupled Wheels.		
	£.	s.	d.	£.	s.	d.	£.	s.	d.	£.	s.	d.
Wages of Engine Drivers and Firemen	2961	9	10	1460	17	1	421	8	2	1079	4	7
Ditto per Mile travelled by the Engine	0	0	1·499									
Ditto per Journey of 111 Miles	0	13	10									
Ditto per Ton Gross Load per Mile	0	0	0·029									
Ditto ditto per Journey	0	0	3·252									
Coals and Firewood	813	11	2	370	3	6	142	7	10	300	19	10
Coke	16810	2	3	7216	2	9	2596	4	0	6997	15	6
Oil	653	2	11	287	13	9	105	17	1	259	12	1
Total Cost of Coals, Firewood, Coke, and Oil	18276	16	4									
Ditto per Mile travelled by the Engine	0	0	9·251									
Ditto per Journey of 111 Miles	4	5	7									
Ditto per Ton Gross Load per Mile	0	0	0·181									
Ditto ditto per Journey	0	1	8·072									
Pumping Engines	226	16	3	121	8	0	46	14	0	98	14	3
Hose Pipes	82	4	3	47	6	6	2	17	0	32	9	0
Fire Tools	8	0	4	4	6	10	0	8	0	3	5	6
Total Cost of Pumping Engines and Hose Pipes, and Fire Tools	357	0	10									
Ditto per Mile travelled by the Engine	0	0	0·181									
Ditto per Journey of 111 Miles	0	1	8									
Ditto per Ton Gross Load per Mile	0	0	0·004									
Ditto ditto per Journey	0	0	0·392									
Cleaners' Wages	3802	1	5	1729	19	8	665	8	10	1406	12	11
Waste and Oil for ditto	337	9	6	153	11	1	59	1	4	124	17	1
Total Cost of Cleaners' Wages, Waste, and Oil	4139	10	11									
Ditto per Mile travelled by the Engine	0	0	2·095									
Ditto per Journey of 111 Miles	0	19	5									
Ditto per Ton Gross Load per Mile	0	0	0·041									
Ditto ditto per Journey	0	0	4·546									
Repairs of Engines	6352	11	11	4447	8	5	443	1	4	1472	2	2
Ditto of Tenders	267	17	11	191	1	10	19	12	1	56	15	5
Cost of Files for Repairs	146	13	0	94	16	10	9	5	10	42	10	4
Ditto Painting ditto	224	13	6	102	4	8	39	6	6	83	2	4
Total Cost of Repairs for Engines, Tenders, Files, and Painting	6991	16	4									

LOCOMOTIVE POWER ACCOUNT,

From 15th December 1839 to 14th June 1840—(*continued*).

	Total.	DIVIDED ACCORDING TO ENGINES HAVING		
		Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Wheels, 5 ft. 6 in. Diameter; One Pair Driving Wheels.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Wheels, 5 ft. 6 in. Diameter; One Pair Driving Wheels.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in; Wheels, 5 ft. Diameter; Coupled Wheels.
COST OF LOCOMOTIVE POWER—(*continued*).	£. s. d.	£. s. d	£. s. d.	£. s. d.
Cost per Mile travelled by the Engine .	0 0 3·539			
Ditto per Journey of 111 Miles . . .	1 12 9			
Ditto per Ton Gross Load per Mile . .	0 0 0·069			
Ditto ditto per Journey	0 0 7·679			
Sundries	573 13 6	261 0 6	100 8 0	212 5 0
Ditto per Mile travelled by the Engine .	0 0 0·291			
Ditto per Journey of 111 Miles . . .	0 2 8			
Ditto per Ton Gross Load per Mile . .	0 0 0·006			
Ditto ditto per Journey	0 0 0·629			
Superintendence, Clerks, Foremen, Watchmen, Office Expenses, &c.	3189 2 0	1451 1 6	558 3 2	1179 17 4
Ditto per Mile travelled by the Engine .	0 0 1·614			
Ditto per Journey of 111 Miles . . .	0 14 11			
Ditto per Ton Gross Load per Mile . .	0 0 0·031			
Ditto ditto per Journey	0 0 3·502			
Total Cost of Passenger Trains . . .	29562 5 7	17245 13 0	5185 2 11	7131 9 8
Ditto of Merchandize Trains	6927 4 2	693 17 11	15 0 10	6218 5 5
Ditto of Locomotive Power	36489 9 9	17939 10 11	5200 3 9	13349 15 1
Ditto per Mile travelled by the Engine .	0 1 6·470	0 1 7·956	0 1 3·039	0 1 6·264
Ditto per Journey of 111 Miles . . .	8 10 10	9 4 7*	6 19 1	8 8 11
Ditto per Ton Gross Load per Mile per Passenger Train	0 0 0·462	0 0 0·558	0 0 0·332	0 0 0·409
Ditto ditto ditto per Merchandize Train .	0 0 0·187	0 0 0·276	0 0 0·253	0 0 0·180
Ditto ditto per Journey per Passenger Train	0 4 3	0 5 2	0 3 1	0 3 9·5
Ditto ditto ditto per Merchandize Train .	0 1 8·75	0 2 6·5	0 2 4	0 1 8
Ditto per Ton Net Load per Mile per Passenger Train	0 0 2·263	0 0 2·731	0 0 1·624	0 0 2·005
Ditto ditto ditto per Merchandize Train .	0 0 0·427	0 0 0·631	0 0 0·580	0 0 0·412
Ditto ditto per Journey per Passenger Train	1 0 11	1 5 3	0 15 0	0 18 6
Ditto ditto ditto per Merchandize Train .	0 3 11·5	0 5 10	0 5 4·5	0 3 9·75
Ditto per Passenger per Mile	0 0 0·254	0 0 0·307	0 0 0·183	0 0 0·225
Ditto ditto per Journey of 111 Miles . .	0 2 4·25	0 2 10	0 1 8·5	0 2 1

* The excess of this amount is due to extensive repairs during this half-year.

EDWARD BURY.

LONDON AND BIRMINGHAM RAILWAY LOCOMOTIVE POWER ACCOUNT,

From 16th June to 15th December 1840, inclusive.

	Total.	DIVIDED ACCORDING TO ENGINES HAVING			
		Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels 5 ft. Diameter.	Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5ft. 6 in. Diameter.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. 6 in. Diameter.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. Diameter; Coupled Wheels.
			All Four-Wheeled	Engines.	
Number of Locomotives	85	1*	42	12	30
Ditto Miles Run since the Opening of the Railway to December 15th, 1840	2,190,493†	. .	1,325,310	196,194	668,989
Average Number of ditto by each Engine	26,077	. .	31,555	16,350	22,300
Number of Miles Run from June 16 to December 15, 1840:—					
With Passenger Trains	452,660	2,421	252,164	103,514	94,561
With Merchandize Trains	105,102	244	9,936	579	94,343
Total	557,762	2,665	262,100	104,093	188,904
Number of Journeys (of 111 Miles):—					
With Passenger Trains	4,078	21¾	2,271¾	932½	852
With Merchandize Trains	947	2¼	89½	5¼	850
Total	5,025	24	2,361¼	937¾	1,702
Greatest Number of Miles Run during the same period by any one Engine	. .	. .	13,410	12,122	9,181
Total Number of Passengers conveyed one Mile (distance 112 miles)	25,931,163				
Ditto (111 Miles) the distance performed by Locomotive Power	25,699,635				
Passengers apportioned among the several Engines, according to Gross Load	. .	158,582	13,146,250	6,623,437	5,771,366
Average Number of Passengers per Trip of Engine	56¾	65½	52	64	61
WEIGHT CONVEYED.	Ton.				
Estimated Gross Weight of each Passenger with his luggage, including the portion of the weight of the Train due to each Passenger	0·568				
Ditto Net Weight of ditto and Luggage (the portion of the weight of the Train due to each Passenger being excluded) 2¼ cwt.	0·1125				
The Net Weight of each Horse is averaged at 9 cwt.	0·22222				
Ditto Carriages with Baggage, 1 ton	1·				

* Harvey Combe (Ballast Engine).

† Exclusive of Harvey Combe.

LOCOMOTIVE POWER ACCOUNT,

From 16th June to 15th December 1840, inclusive—(*continued*).

	Total.	DIVIDED ACCORDING TO ENGINES HAVING			
		Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. Diameter.	Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. 6 in. Diameter.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. 6 in. Diameter.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. Diameter; Coupled Wheels.
WEIGHT CONVEYED—(*continued*).	Tons.	Tons.	Tons.	Tons.	Tons.
The Net Weight of each Dog is averaged at 42 lbs.	0·01873				
Ditto Mail Bags, per diem, 4 tons, 8 cwt. 2 qrs.	4·425				
Ditto Cattle, 5½ cwt.	0·275				
Ditto Sheep, ¾ cwt.	0·0375				
Ditto Pigs, 1 cwt.	0·05				
Gross Load conveyed one Mile:—					
Passenger Trains	19,126,547	118,022	9,783,889	4,929,388	4,295,248
Merchandize Trains	10,075,712	20,328	711,212	45,048	9,299,124
Total	29,202,259	138,350	10,495,101	4,974,436	13,594,372
Net Load conveyed one Mile:—					
Passenger Trains	3,790,728	23,391	1,939,088	976,965	851,284
Merchandize Trains	4,912,183	9,911	346,735	21,962	4,533,575
Total	8,702,911	33,302	2,285,823	998,927	5,384,859
Average Gross Load per each Journey of the Engine (111 Miles):—					
Passenger Trains	42·254	48·749	38·800	47·621	45·423
Merchandize Trains	95·866	83·311	71·579	77·803	98·567
Average Net Load for each Journey of the Engine (111 Miles):—					
Passenger Trains	8·374	9·662	7·690	9·438	9·002
Merchandize Trains	46·737	40·619	34·897	37·931	48·054
Average Net Load to every 100 tons of Gross Load:—					
Passenger Trains	19·819				
Merchandize Trains	48·753				

LOCOMOTIVE POWER ACCOUNT,

From 16th June to 15th December 1840, inclusive—(*continued*).

	Total.	DIVIDED ACCORDING TO ENGINES HAVING			
		Cylinders 12 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. Diameter.	Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. 6 in. Diameter.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. 6 in. Diameter.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. Diameter; Coupled Wheels.
RATE OF SPEED.	Hours. Minutes.	Hours. Minutes.	Hours. Minutes.	Hours. Minutes.	Hours. Minutes.
Total Time the Passenger Trains were in Motion	17371 34	108 42	9770 31	3782 26	3709 55
Average Time per Journey (111 Miles) .	4 15	4 59	4 18	4 3	4 21
	Miles per Hour.	Miles per Hour.	Miles per Hour.	Miles per Hour.	Miles per Hour.
Average Speed of Passenger Trains . .	26·080	22·271	25·808	27·367	25·489
Ditto Merchandize Trains	20·				
COKE CONSUMED.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.	Tons. Cwts.
Total Quantity	9844 6	52 13	4279 13	1611 18	3900 2
	lbs.	lbs.	lbs.	lbs.	lbs.
Quantity per Mile	39·535	44·254	36·575	34·687	46·247
	Tons. cwts. lbs.	Tons. cwts. qrs. lbs.	Tons. cwts. qrs.	Tons. cwts. qrs. lbs.	Tons. cwts. qrs. lbs.
Ditto per Journey	1 19 20	2 3 3 12	1 16 1	1 14 1 14	2 5 3 9
	lbs.	lbs.	lbs.	lbs.	lbs.
Ditto per Ton of Gross Load per Mile .	0·755	0·853	0·913	0·726	0·643
Ditto ditto per Journey	83·818	94·621	101·389	80·568	71·333
Ditto per Hour	974$\frac{1}{2}$	975$\frac{1}{2}$	933$\frac{3}{4}$	947$\frac{1}{4}$	1036$\frac{2}{3}$
OIL CONSUMED.	Quarts.	Quarts.	Quarts.	Quarts.	Quarts.
Total Quantity	20050$\frac{1}{2}$	133$\frac{1}{2}$	9196	3242	7479
Quantity per Mile	0·036	0·050	0·035	0·031	0·040
Ditto per Journey	3·990	5·560	3·895	3·457	4·395
COST OF COKE.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
Total Cost	19420 13 10	103 9 5	8467 8 8	3150 5 3	7699 10 6
	d.	d.	d.	d.	d.
Cost per Mile	8·356	9·318	7·753	7·263	9·782
	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
Ditto per Journey (111 Miles) . . .	3 17 3	4 6 2	3 11 8	3 7 2	4 10 6
	s. d.	s. d.	s. d.	s. d.	s. d.
Ditto per Ton of Gross Load per Mile .	0 0·160	0 0·179	0 0·194	0 0·152	0 0·136
Ditto ditto per Journey	1 5·760	1 7·869	1 9·534	1 4·872	1 3·096
Ditto per Hour	17 2	17 1$\frac{4}{10}$	16 6	16 6$\frac{4}{10}$	18 3$\frac{1}{4}$
COST OF OIL.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
Total Cost	835 8 9	5 11 3	383 3 4	135 1 8	311 12 6
	s. d.	s. d.	s. d.	s. d.	s. d.
Cost per Mile	0 0·360	0 0·501	0 0·351	0 0·311	0 0·396
Ditto per Journey (111 Miles) . . .	3 3·902	4 7·604	3 2·945	2 10·571	3 7·947

LOCOMOTIVE POWER ACCOUNT,

From 16th June to 15th December 1840, inclusive—*continued.*

	Total.	DIVIDED ACCORDING TO ENGINES HAVING			
		Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5ft. Diameter.	Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. 6 in. Diameter.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. 6 in. Diameter.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. Diameter; Coupled Wheels
COST OF REPAIRS OF ENGINES AND TENDERS, INCLUDING PAINTING, &c.	*£. s. d.*	*£. s. d.*	*£. s. d.*	*£. s. d.*	*£. s. d.*
Total Cost	8247 1 2	73 12 8	4739 18 7	732 17 10	2700 12 1
	d.	*d.*	*d.*	*d.*	*d.*
Cost per Mile	3·549	6·631	4·340	1·690	3·430
	£. s. d.	*£. s. d.*	*£. s. d.*	*s. d.*	*£. s. d.*
Ditto per Journey (111 Miles) . . .	1 12 10	3 1 4	2 0 2	15 7½	1 11 9
	d.	*d.*	*d.*	*d.*	*d.*
Cost per Ton of Gross Load per Mile .	0·068	0·128	0·109	0·035	0·048
Ditto ditto per Journey	7·523	14·178	12·031	3·925	5·291
COST OF LOCOMOTIVE POWER.	*£. s. d.*	*£. s. d.*	*£. s. d.*	*£. s. d.*	*£. s. d.*
Wages of Engine Drivers and Firemen .	3470 10 7	16 11 8	1630 17 1	647 13 6	1175 8 4
Coals and Firewood	748 4 1	3 11 6	351 12 0	139 12 7	253 8 0
Coke	19420 13 10	103 9 5	8467 8 8	3150 5 3	7699 10 6
Oil	835 8 9	5 11 3	383 3 4	135 1 8	311 12 6
Pumping Engines at Stations, and Supply of Water at Birmingham	862 4 8	4 2 5	405 3 6	160 18 4	292 0 5
Hose Pipes	84 2 0	0 19 0	43 14 0	9 10 0	29 19 0
Fire Tools	11 5 4	0 8 0	5 6 4	1 10 4	4 0 8
Cleaners' and Labourers' Wages . . .	4093 18 0	19 11 3	1923 15 8	764 1 0	1386 10 1
Waste and Oil for Ditto	393 7 2	1 17 7	184 16 11	73 8 2	133 4 6
Total	29919 14 5	156 2 1	13395 17 6	5082 0 10	11285 14 0
Repairs of Engines	7221 7 8	67 16 3	4335 3 10	590 10 2	2227 17 5
Ditto of Tenders	363 16 5	1 1 1	70 19 2	31 9 3	260 6 11
Cost of Files for Repairs	177 7 9	2 9 0	106 2 4	20 10 2	48 6 3
Ditto Painting	231 2 6	1 2 1	108 12 3	43 2 8	78 5 6
Cost of Working Stationary Engine at Wolverton (forming part of Repairs) .	97 16 7	0 9 4	45 19 5	18 5 2	33 2 8
Repairs of Tender Wheels and Springs .	155 10 3	0 14 11	73 1 7	29 0 5	52 13 4
Total	8247 1 2	73 12 8	4739 18 7	732 17 10	2700 12 1
Accident Account	139 19 7	0 13 4	65 15 7	26 2 6	47 8 2
Gas at Engine Houses, Camden, Wolverton, and Birmingham	317 4 7	1 10 4	149 1 6	59 4 0	107 8 9
Superintendent, Clerks, Office Charges, Foremen, &c.	4743 11 1	22 13 4	2229 1 11	885 5 0	1606 10 10
Total	5200 15 3	24 17 0	2443 19 0	970 11 6	1761 7 9
Aggregate of Totals . .	43367 10 10	254 11 9	20579 15 1	6785 10 2	15747 13 10

LOCOMOTIVE POWER ACCOUNT,

From 16th June to 15th December 1840, inclusive—(*continued*).

COST OF LOCOMOTIVE POWER—(*continued*).	Total Cost.	Cost per Day (183 Days).	Cost per Mile travelled by Engine.	Cost per Journey of 111 Miles.	Cost per Ton Gross Load per Mile.	Cost per Ton Gross Load per Journey.
	£ s. d.	£. s. d.	d.	£. s. d.	d.	d.
Wages of Engine Drivers and Firemen .	3470 10 7	18 19 3½	1·494	0 13 10	0·028	3·166
Coals, Firewood, Coke, and Oil . . .	21004 6 8	114 15 6½	9·037	4 3 7	0·172	19·161
Pumping Engines, Hose Pipes, and Fire Tools	957 12 0	5 4 8	0·414	0 3 10	0·008	0·874
Labourers and Cleaners, and Cotton Waste and Oil for Ditto	4487 5 2	24 10 5	1·929	0 17 10	0·037	4,094
	29919 14 5	163 9 11	12·874	5 19 1	0·245	27·295
Repairs of Engines and Tenders, including Files, Painting, &c.	8247 1 2	45 1 4	3·550	1 12 10	0·068	7·524
Sundries, viz., Accident Account, and Gas at Stations	457 4 2	2 9 11½	0·196	0 1 10	0·004	0·417
Superintendent, Clerks, Office Charges, Foremen, Watchmen, &c. &c. . . .	4743 11 1	25 18 5	2·041	0 18 10	0·039	4·327
Total	43367 10 10	236 19 7½	18·661	8 12 7	0·356	39·563

	Total.	DIVIDED ACCORDING TO ENGINES HAVING Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. Diameter.	Cylinders, 12 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. 6 in. Diameter.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. 6 in. Diameter.	Cylinders, 13 in. Diameter; Stroke of Piston, 18 in.; Driving Wheels, 5 ft. Diameter; Coupled Wheels.
	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
Passenger Trains	34661 0 10	231 5 7	19815 7 10	6731 8 9	7882 18 8
Merchandize Trains	8706 10 0	23 6 2	780 15 8	37 13 0	7864 15 2
Total	43367 10 10	254 11 9	20596 3 6	6769 1 9	15747 13 10
	d.	d.	d.	d.	d.
Cost per Mile travelled by Engine . .	18·661	22·927	18·859	15·607	20·007
	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
Ditto per Journey of 111 Miles . . .	8 12 7	10 12 1	8 14 5	7 4 4	9 5 1
Cost per Ton of Gross Load per Mile:—					
Passenger Trains	0 0 0·435	0 0 0·470	0 0 0·486	0 0 0·328	0 0 0.440
Merchandize Trains	0 0 0·207	0 0 0·275	0 0 0·263	0 0 0·201	0 0 0·203
Cost per Ton of Gross Load per Journey:—					
Passenger Trains	0 4 0¼	0 4 4¼	0 4 6	0 3 0½	0 4 1
Merchandize Trains	0 1 11	0 2 6½	0 2 5¼	0 1 10¼	0 1 10½
Cost per Ton of Net Load per Mile:—					
Passenger Trains	0 0 2·194	0 0 2·373	0 0 2·452	0 0 1·654	0 0 2·222
Merchandize Trains	0 0 0·425	0 0 0·564	0 0 0·540	0 0 0·411	0 0 0·416
Cost per Ton of Net Load per Journey:—					
Passenger Trains	1 0 3½	1 1 11½	1 2 8¼	0 15 3½	1 0 6½
Merchandize Trains	0 3 11¼	0 5 2½	0 5 0	0 3 9½	0 3 10¼
Cost per Passenger per Mile	0 0 0·247	0 0 0·267	0 0 0·276	0 0 0·186	0 0 0·250
Ditto ditto per Journey	0 2 3¼	0 2 5½	0 2 6½	0 1 8½	0 2 3¾

LOCOMOTIVE POWER ACCOUNT.

REPAIRS OF ENGINES AND TENDERS,

From the Commencement of their Running to the 15th December 1840.

	Total.	Divided according to those that have run				
		Under 10,000 Miles.	10,000 and under 20,000.	20,000 and under 30,000.	30,000 and under 40,000.	40,000 and under 50,000.
Number of Engines .	84	4	19	33	19	9
Total Miles Run . .	2,190,493	29,996	311,142	814,570	643,008	391,777
Average Number of Miles per Engine .	26,077	7,499	16,376	24,684	33,842	43,531
	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.	£. s. d.
Total Cost of Repairs	25037 1 6	137 0 3	2441 4 6	10163 10 4	7493 9 8	4801 16 9
Average Cost per Engine	298 1 2	34 5 1	128 9 9	307 19 9	394 7 11	533 10 9
	d.	d.	d.	d.	d.	d.
Ditto per Mile . .	2·743	1·096	1·833	2·994	2·797	2·941
	£. s. d.	s. d.	s. d.	£. s. d.	£. s. d.	£. s. d.
Ditto per Journey .	1 5 4½	10 1½	17 5	1 7 8½	1 5 10½	1 7 2½

EDWARD BURY.

LONDON:
Printed by W. Clowes and Sons,
14, Charing Cross.

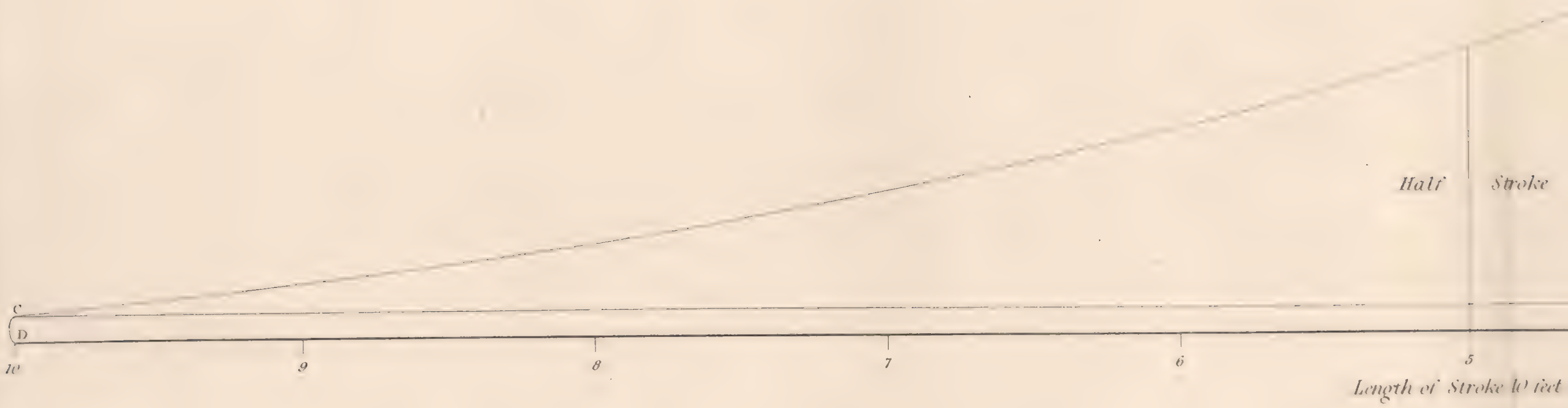
INDICATOR D

FROM THE

HUEL TOWAN

ENLARGED FROM THE ORIGINAL, VIDE TRANS. IN

STEAM IN THE BOILERS 61.8 LBS ON



The action of the Indicator in tracing a diagram is too well known to require description. In computing all Mr. Henwood's diagrams the p stroke forms no part of the power exerted during the working stroke.*

The working stroke of the engine terminated at C, when the equilibrium valve was opened. The steam's elasticity in the cylinder was then 7 filling the space beneath the piston, and the pipe of communication, whilst the piston ascended in equilibrio. The equilibrium valve w end of its course, when the exhausting valve was opened. The steam's elastic force above the piston being then virtually increased by the the quantity of steam recovered, & forming the cushion, at an elasticity of 10.7 lbs. per sq. in. After a rest of 4.8 secds. the steam nearly 19 lbs. per sq. in. The working stroke then commenced, the steam arriving at its maximum elasticity at B when the piston ha until the closing of the valve. This operation is not instantaneous, being effected by the descent of the plug rod. The diagram rather quarter of the stroke. *Vide Henwood. Trans. Inst. C. E. Vol. 2. p. 49.

Josiah Parkes del.

Institution of Civil Eng

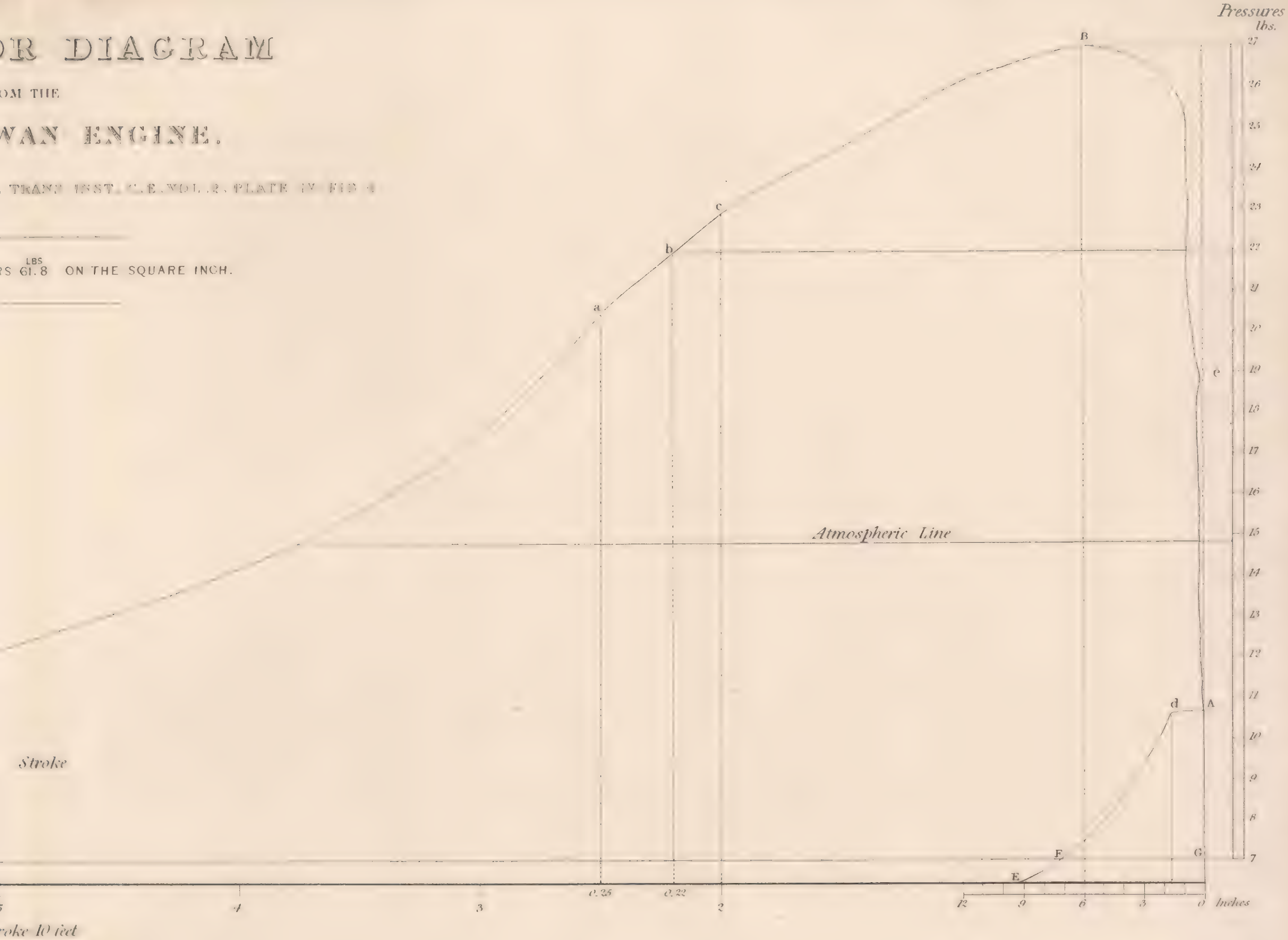
OR DIAGRAM

OM THE

WAN ENGINE.

TRANS INST. C.E. VOL. 2. PLATE IV FIG 4

RS 61.8 LBS ON THE SQUARE INCH.



ams the pressures must be taken above the line C G, as the quantity of expansion suffered by the steam during the return

was then 7^{lbs} per sq. in. The space C D E F represents the amount of the steam's expansion during the return stroke, caused by its
n valve was closed at E. The steam's compression then commenced, and continued till the piston arrived at d, within 1¾ in. of the
sed by the vacuum formed beneath it, the return stroke nearly ceased, and the engine came finally to rest at A. The space A F G represents
the steam valve was opened by the cataract, but the engine's motion did not ensue till the steam attained at e, an elastic force of
piston had descended 6 inches, from which period of the stroke the steam expanded with great rapidity, though not with uniformity
am rather indicates that the closing of the valve commenced at c, and terminated at a, when the piston had paſsed through a

S. Bellin ſculp.

INDICATOR DIAGRAM

FROM THE

EAST CRINNIS ENGINE.

ENLARGED FROM THE ORIGINALS. VIDE TRANS. INST. C.E. VOL. 2. PLAT

STEAM IN THE BOILERS 36.8 LBS ON THE SQUARE INCH.

Length of Stroke 10 feet 3

STEAM IN THE BOILERS 26.3 LBS ON THE SQUARE INCH.

Length of Stroke 10 fe

Vide explan... Engine Diagr

GRAMS

GINE,

ARE INCH.

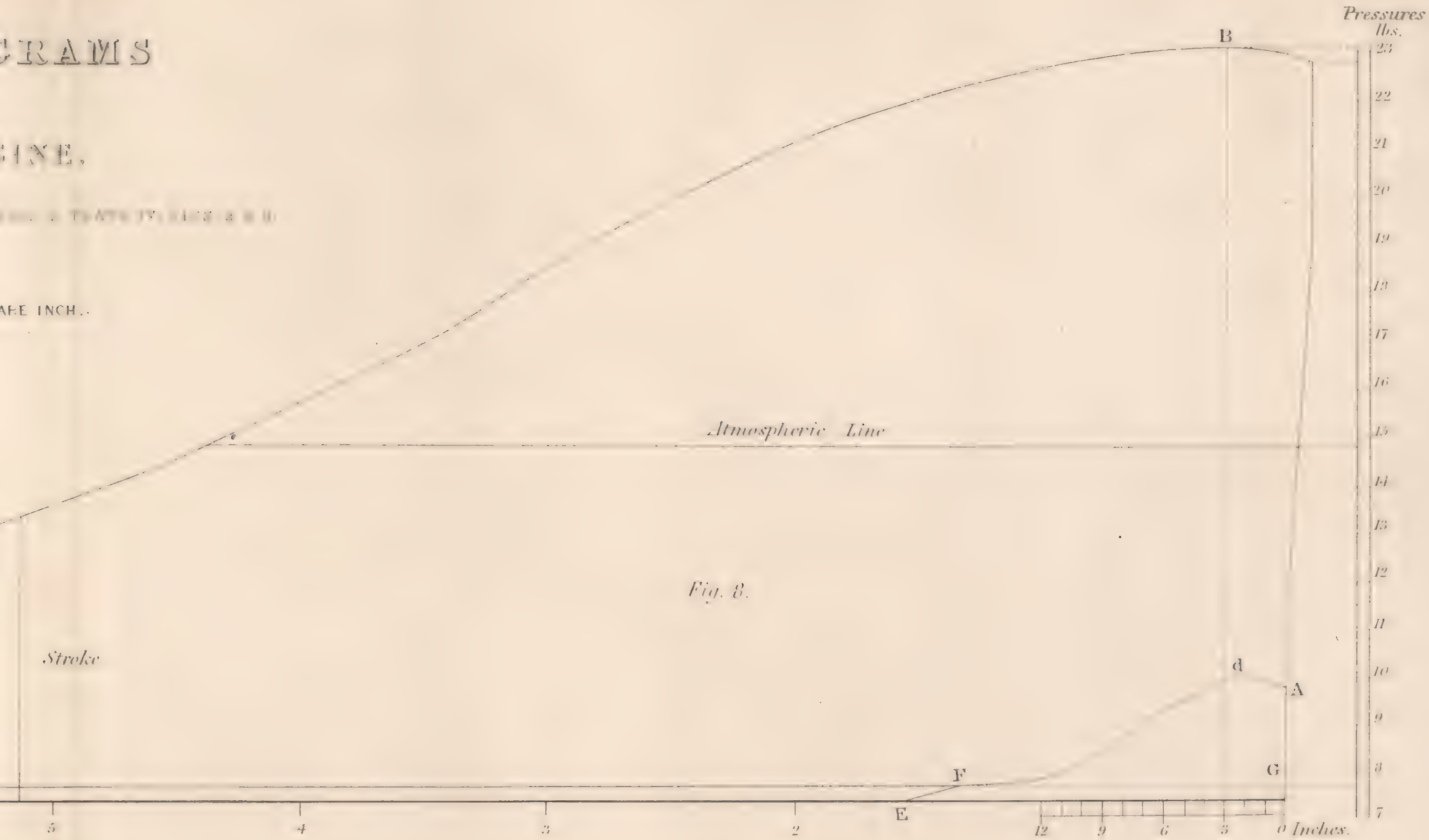


Fig. 8.

ke 10 feet 3 inches.

RE INCH

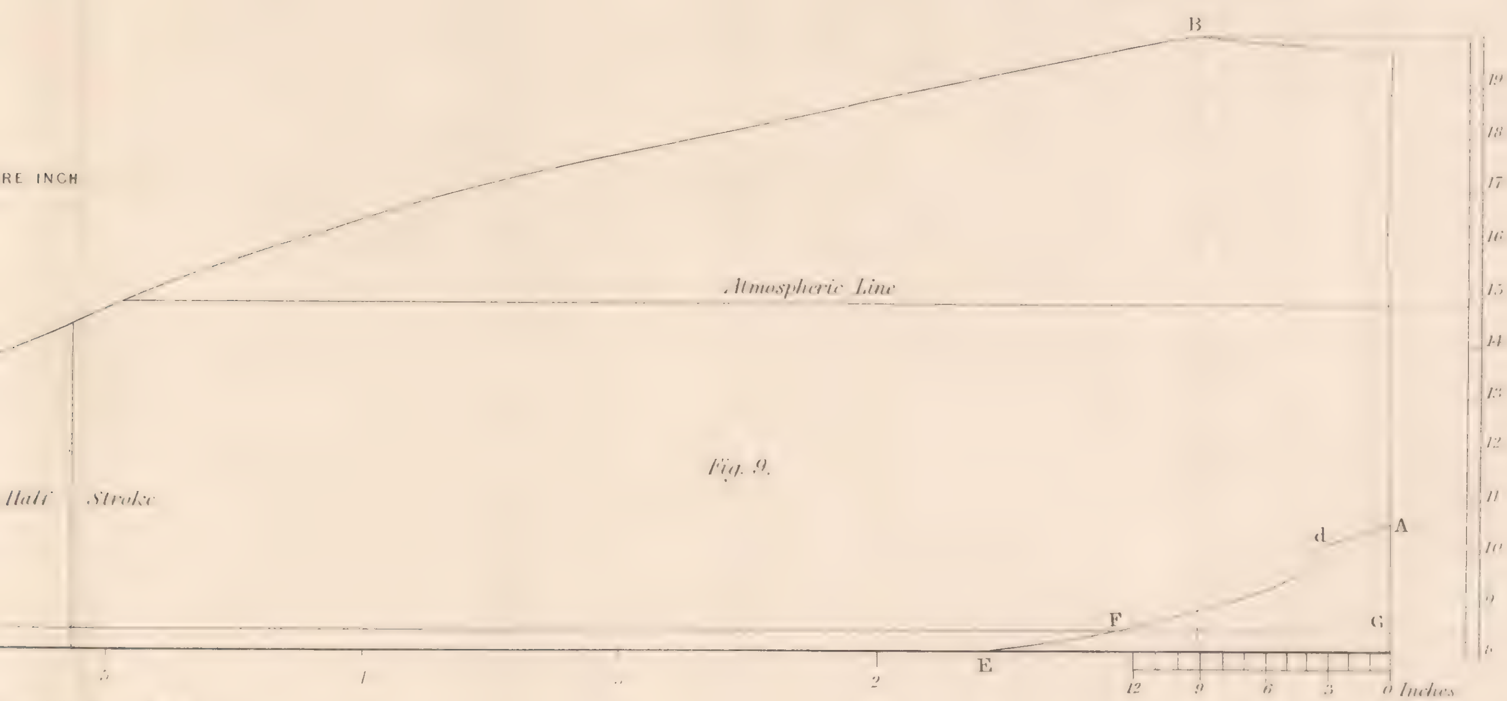


Fig. 9.

Stroke 10 feet 3 inches

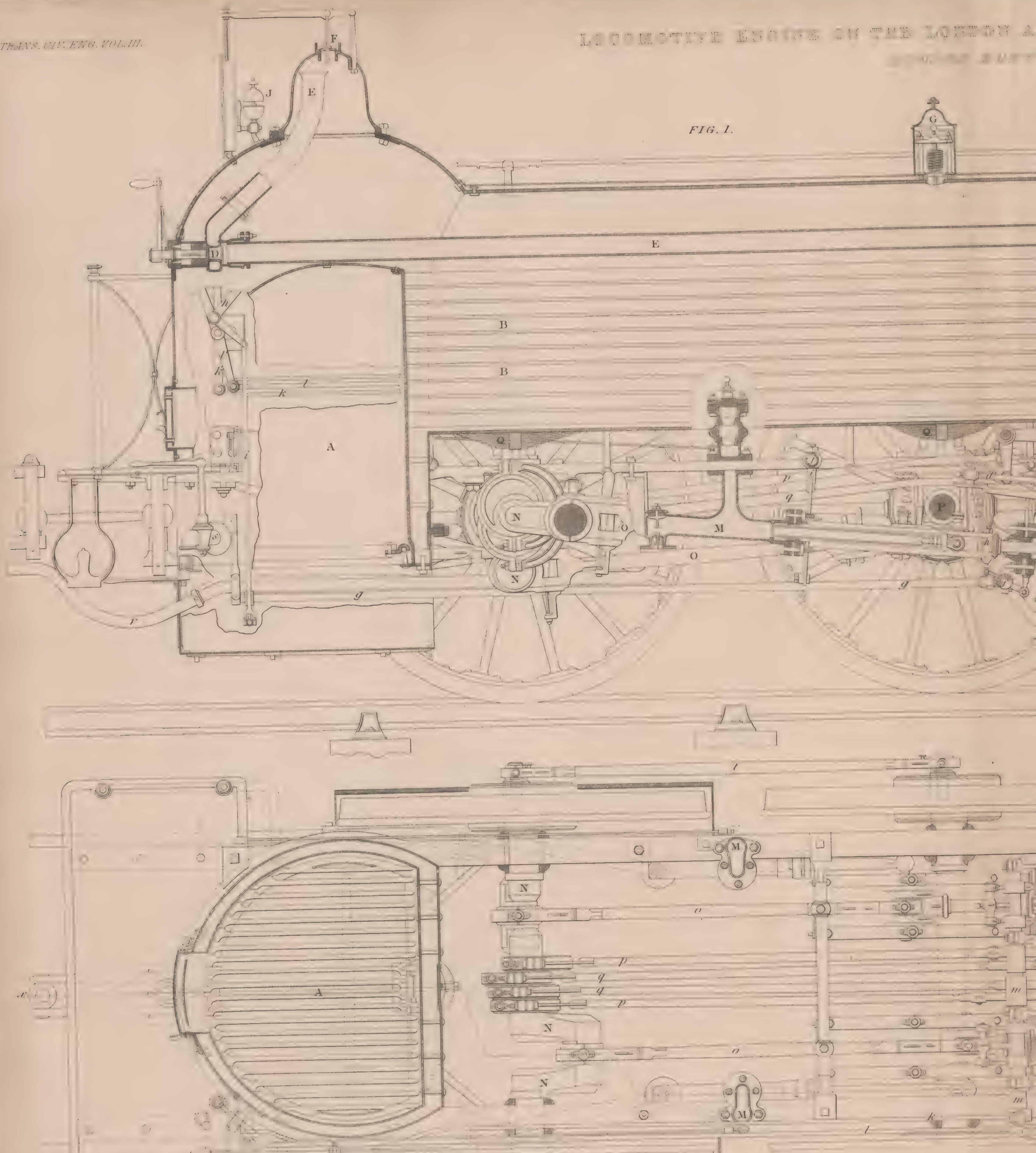
ngine Diagram. The letters refer to similar parts

S.Bellin sculp.

of Civil Engineers, 1840.

LOCOMOTIVE ENGINE ON THE LONDON A

FIG. 1.



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...STER AND BIRMINGHAM RAILWAY.

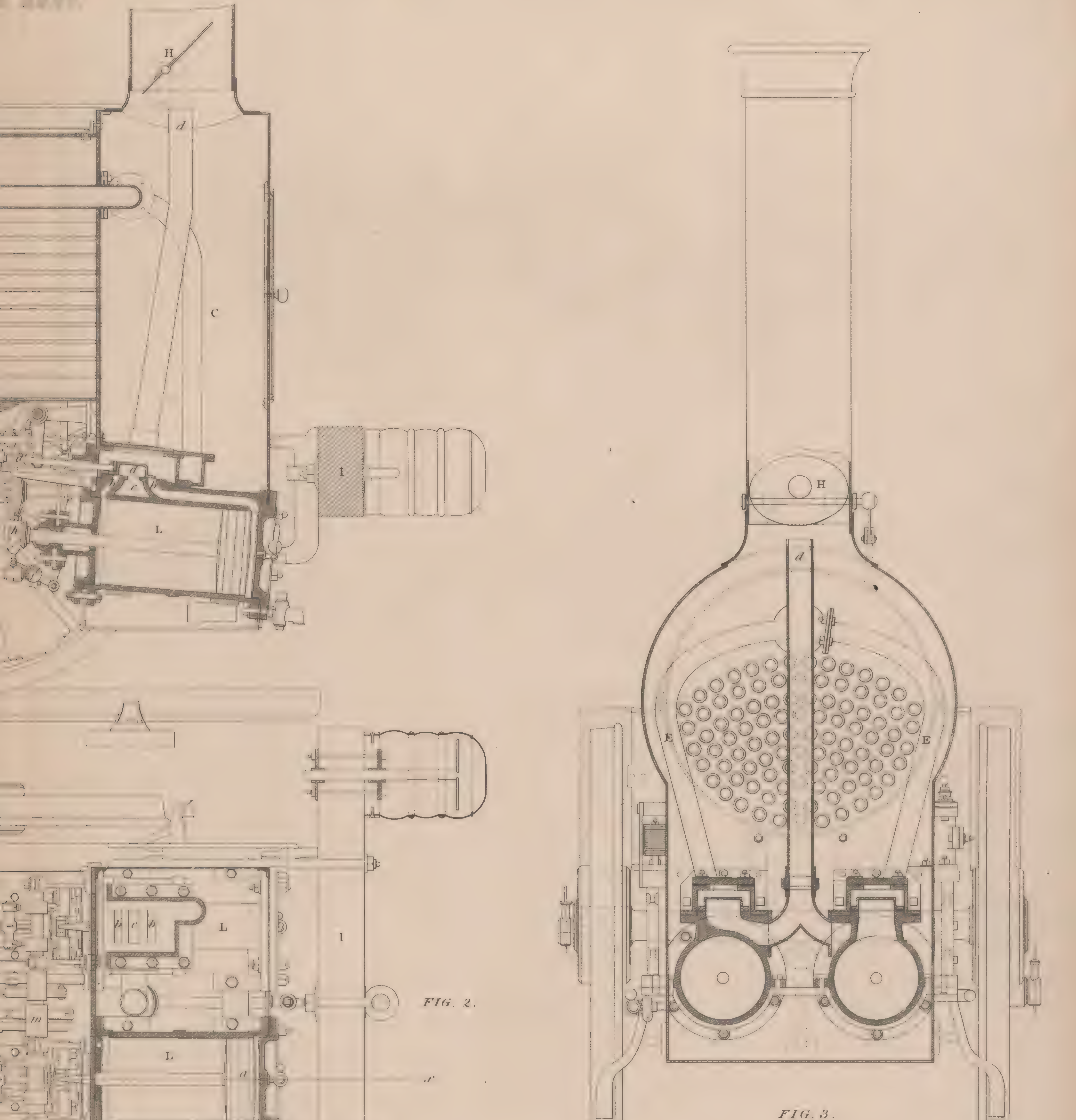
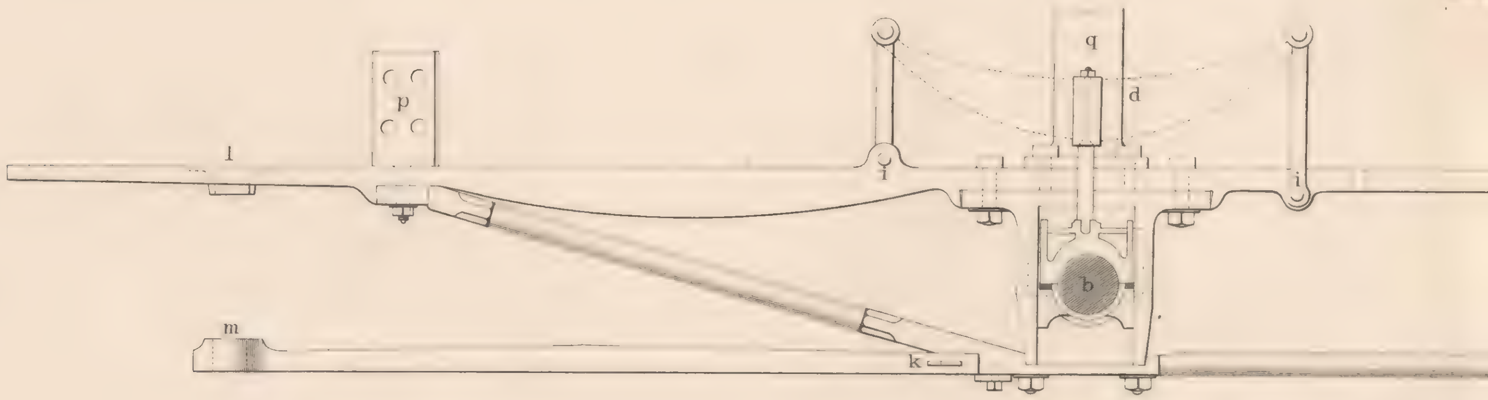


FIG. 2.

FIG. 3.

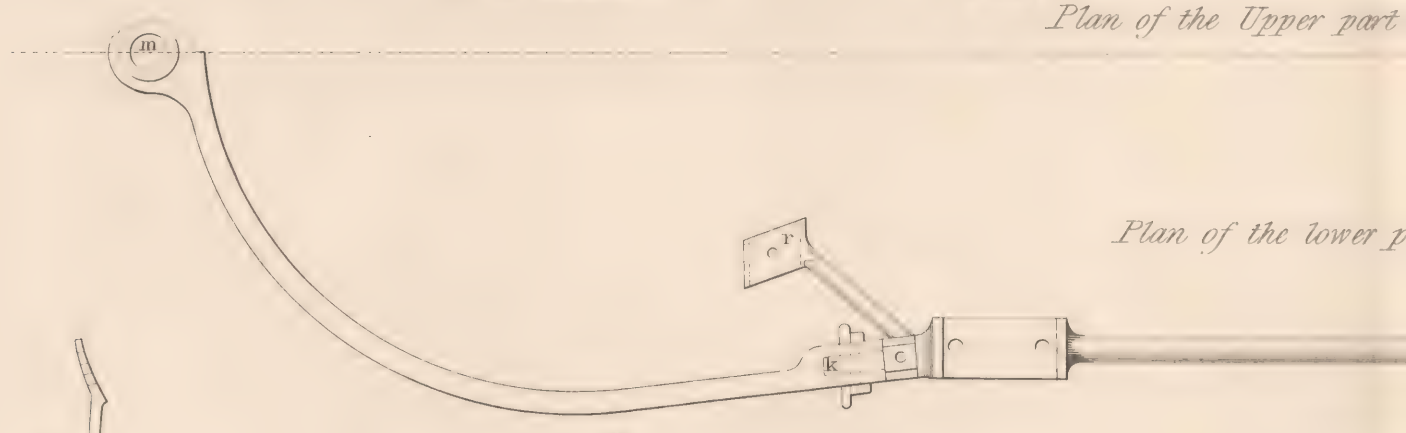
...ivil Engineers 1841.

LOCOMOTIVE ENGINE ON THE

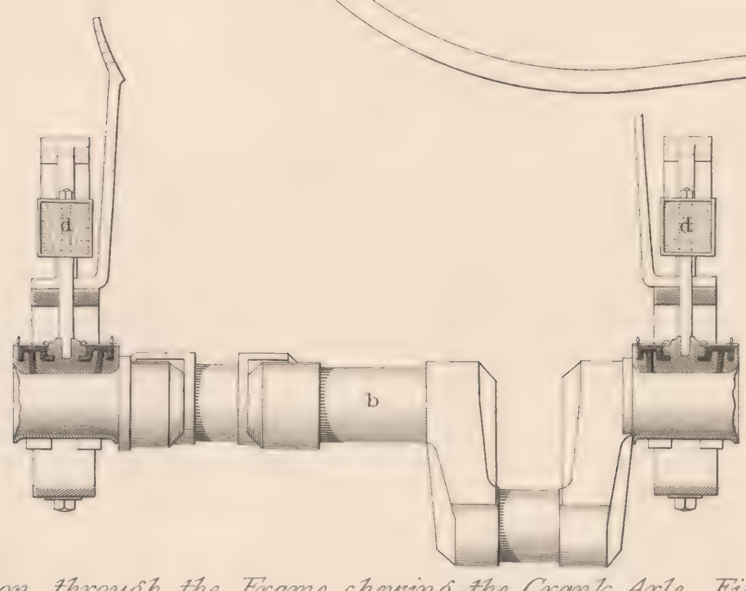


Elevation of Fram

Plan of the Upper part

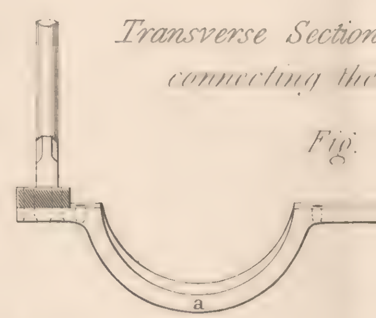


Plan of the lower p



Section through the Frame, shewing the Crank Axle, Fig. 4.

Transverse Section
connecting the
Fig.



12 9 6 3 0 1 2
Scale of

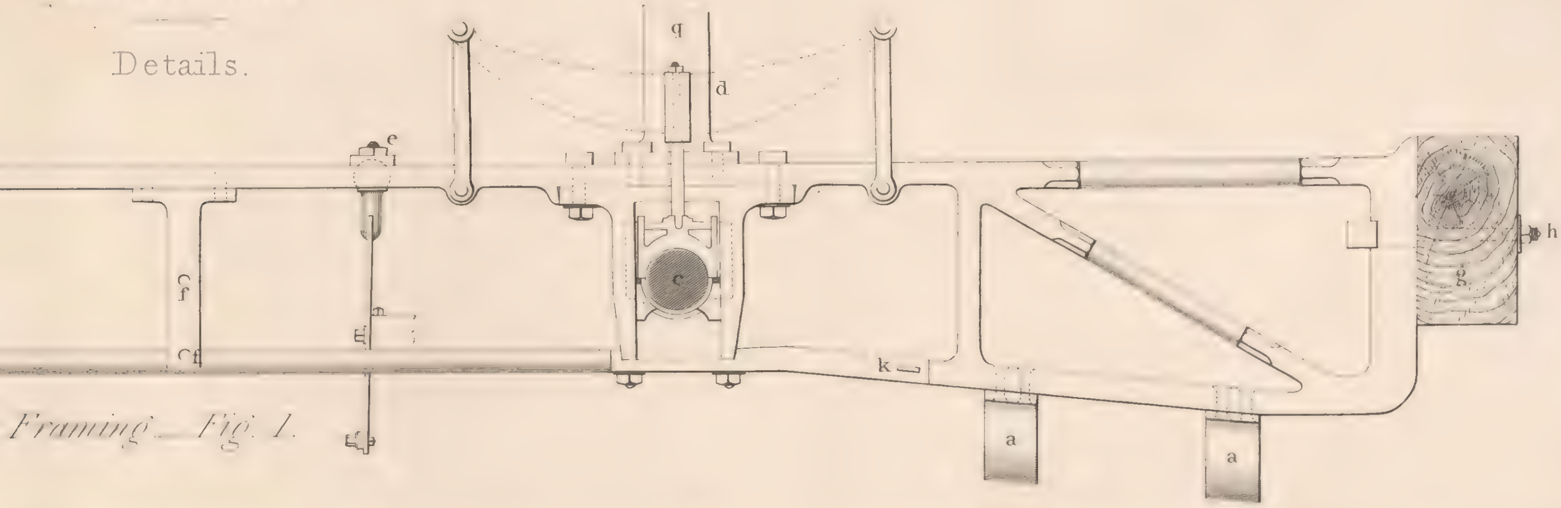
Drawn by E. O. Manby.
Reduced by Frederick Rumble.

Institution of Civil E

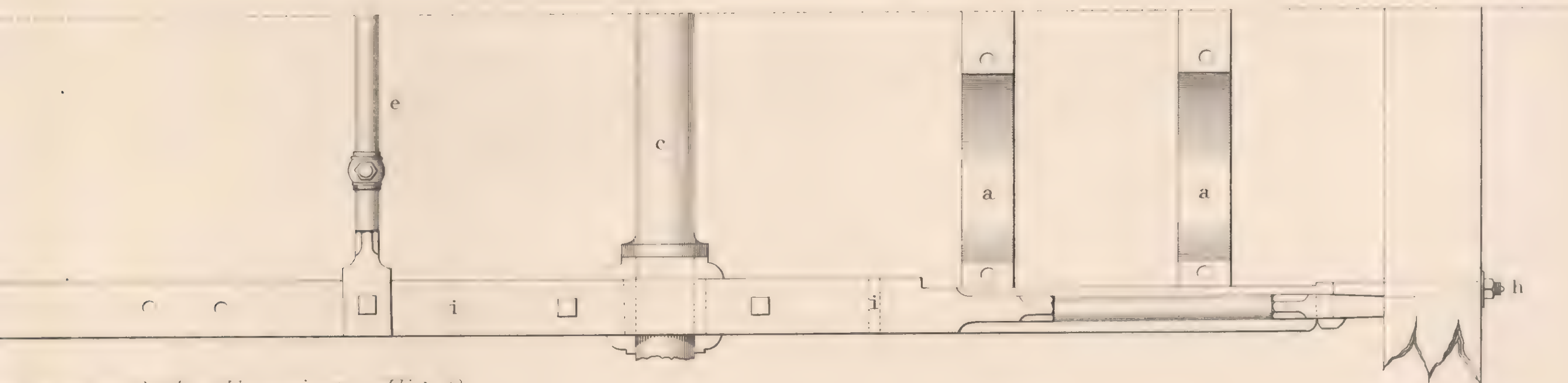
THE LONDON AND BIRMINGHAM RAILWAY.

EDWARD BURY

Details.

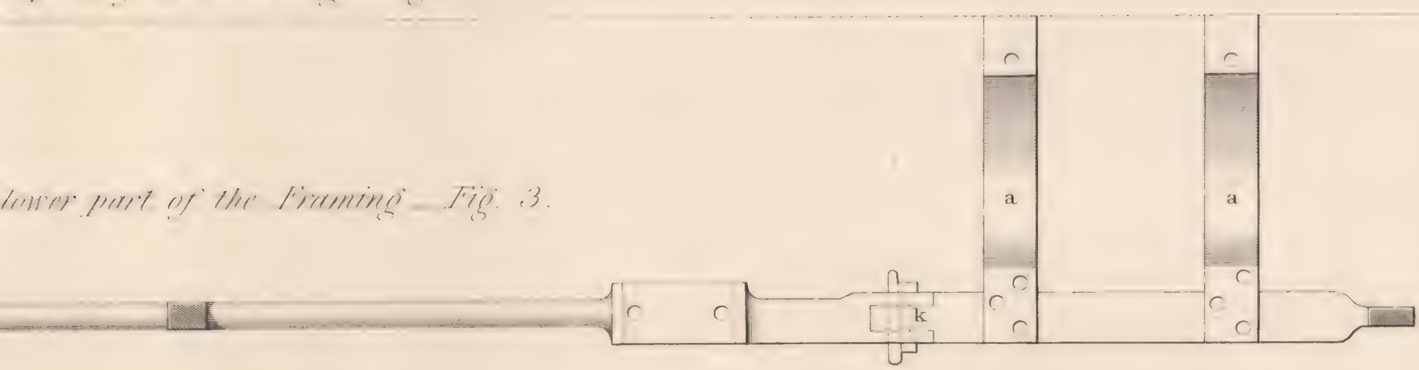


Framing _ Fig. 1.



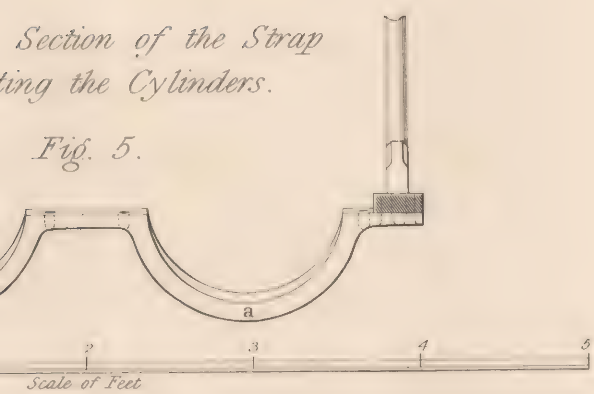
r part of the Framing _ Fig. 2.

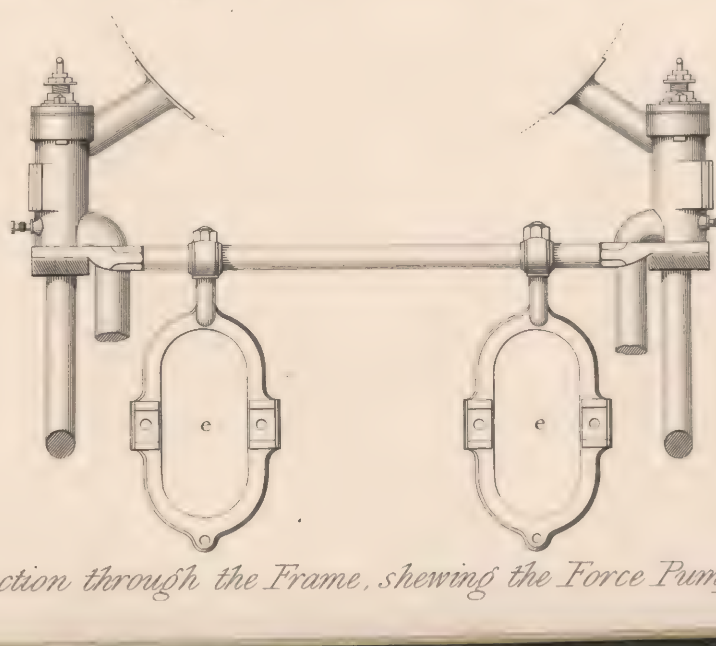
lower part of the Framing _ Fig. 3.



Section of the Strap
ting the Cylinders.

Fig. 5.





Section through the Frame, shewing the Force Pumps.